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Walden D & Nou S (eds)

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Kakadu National Park Landscape Symposia Series 2007–2009

Symposium 1: Landscape Change Overview 17–18 April 2007, South Alligator Inn, Kakadu National Park

Edited by D Walden[1] & S Nou[2]

[1] Environmental Research Institute of the Supervising Scientist

[2] Parks Australia North

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Editors of this report:

Dave Walden – Environmental Research Institute of the Supervising Scientist, GPO Box 461, Darwin NT 0801, Australia

Suthidha Nou – Kakadu National Park, Parks Australia North, PO Box 71, Jabiru NT 0886, Australia

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Supervising Scientist
Department of the Environment, Water, Heritage and the Arts
GPO Box 461, Darwin NT 0801 Australia

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List of participants

Name		Group
Alderson	Jessie	BOM, KNP, TO
Atkins	Sally-Anne	KNP
Baird	Fred	KNP
Banggalang	Michael	BOM, TO
Bartolo	Renee	ERISS
Bayliss	Peter	KRAC & ERISS
Bellairs	Sean	CDU
Blyth	Mary	KNP
Boggs	Guy	CDU
Bradshaw	Corey	CDU
Buliwana	Kevin	TO-Arnhem Land
Butler	Peter	KNP
Cabral	Sergio	USC
Cahill	Paddy	KNP
Campbell	Bruce	CDU, KRAC
Chapman	Steve	formerly KNP
Christophersen	Jane	TO, BOM
Christophersen	Carol	NLC/PAN
Cleland	Sam	Bureau of Met
Cochrane	Peter	DEW, BOM
Delahunt	Anne-Marie	PAN, KRAC
Delaney	Robyn	NRETA
Dewar	Graham	Gundjehimi
Dobson	Craig	ERA
Douglas	Michael	KRAC, CDU
Dunn	Matt	KNP
Edwards	Andrew	NRETA
Ferdinands	Keith	NRETA
Franklin	Don	CDU
Gardener	Mark	EWL
Gorst	Mick	KNP
Harty	Bryan	KNP
Hill	Terry	KNP
Hooke	Amber	EWL
Humphrey	Chris	ERISS
Jones	David	KRAC & ERISS
Kennett	Rod	NAILSMA, CDU
Kyle	Geoff	Gundjeihmi
Lawson	Violet	TO
Leach	Greg	NRETA

Name		Group
Lee	Jeffrey	BOM, KNP, TO
Lehmann	Caroline	CDU
Liddle	Dave	NRETA
Madycki	Zig	KNP
Margarulu	Yvonne	BOM, TO
McMahon	Clive	CDU
Meade	Glenn	KNP
Muller	Rob	KNP
Murphy	Brett	NRETA
Nayinggul	Jacob	BOM, TO
Nayinggul	Alfred	TO
Nock	Edward	ERA
Nou	Tida	KNP
O’Loughlin	Gabrielle	KNP
O'Dea	Anne	KNP
Palmer	Carol	NRETA
Paul	Stuart	KNP
Petty	Aaron	CDU
Phillips	Bill	Facillitator
Pickworth	Anna	KNP
Prior	Lynda	CDU
Riley	Jan	CDU
Russell-Smith	Jeremy	KRAC/NRETA
Salau	Buck	KNP
Schinkel	Hank	KNP
Schmid	Michael	NRETA
Smit	Neil	NRETA marine
Smith	Natasha	KNP
Smith	Howard	NLC
Styles	Paul	KNP
Tremblay	Pascal	KRAC, CDU
Valentine	Eric	CDU
Wasson	Bob	CDU
Waterman	Peter	USC
Watt	Felicity	NRETA
Wellings	Andrew	KNP
Williams	Denise	Traditional Owner
Williams	Nancy	KRAC
Winderlich	Steve	KNP
Woinarski	John	NRETA
Yibarbuk	Dean	TO – Arnhem Land
?	Shirley	TO – Arnhem Land

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The success of the Landscape Change Symposium was due in no small part to efforts of the symposium steering committee and staff from the Natural and Cultural Programs Section of Kakadu National Park, in particular Tida Nou and Anne O'Dea. The symposium steering committee made up of Steve Winderlich (chair, Parks Australia North), Dr Peter Bayliss (***eriss***), Dr Renée Bartolo (***eriss***), Dr Alan Andersen (CSIRO), Dr Michael Douglas (CDU), Dr Linda Prior (CDU), Aaron Petty (PhD candidate CDU) and Emma Woodward (CSIRO), provided essential expertise and input. They are all very busy people who gave generously of their time which is greatly appreciated. Dr Bill Phillips of MainStream Environmental Consulting Pty Ltd is also acknowledged for the excellent job he did as facilitator.

1 Introduction

The concept of the Kakadu National Park Landscape Change Symposium was conceived at a meeting in early 2006 between Steve Winderlich, the newly appointed Manager of the Natural and Cultural Programs Section of Kakadu National Park (KNP), Dr Peter Bayliss of ***eriss***, and Aaron Petty and Caroline Lehmann – both PhD students at CDU. The aim of the meeting was to look for ways to apply some of the recent research that had focused on landscape change in KNP and identify future research directions. The consensus was that the best way to do this would be to convene a symposium and the Landscape Change Symposium was born.

The aim of the Landscape Change Symposium was to have an effective two-way transfer of knowledge between Kakadu National Park staff, researchers, the Kakadu Research Advisory Committee (KRAC) members, stakeholders and Traditional Owners on issues pertinent to:

- landscape change
- change processes generally
- management implications and recommendations
- visions of landscape health and resilience
- future research directions, and to
- ensure that the outcomes of research are integrated in a timely and sensitive way into park management.

The objective was to place this knowledge in a management context and pose questions to Park Managers and Traditional Owners regarding future management frameworks and research directions. It was anticipated that the findings of this forum would feed into a series of more focused symposiums and workshops. The topics of these forums were to be Weed, Fire, Feral Animal Management, Climate Change and a final Ecological Risk and Adaptive Management symposium which would essentially be the summary and synthesis forum for the preceding symposiums and workshops.

The symposium was held at the Aurora Kakadu (South Alligator). It was originally scheduled for 6 and 7 March 2007 but just to emphasise the need to focus on agents of change an extreme flooding event that coincided with these dates meant that the symposium had to be rescheduled to 17 and 18 April 2007. Over one hundred participants from a wide range of stakeholders including government agencies, academic institutions, landholders, Traditional Owners and Indigenous Associations attended. These included Parks Australia, ***eriss***, CSIRO, CDU, Northern Territory Government, NLC, Kakadu Board of Management, Kakadu Research Advisory Committee, Gundjeihmi Association, Werenbun Association, WWF, Energy Resources of Australia Ltd and EWLS.

Topics presented at the symposium included:

- An overview of landscape change in Kakadu
- Savanna dynamics
- Floodplain dynamics
- Riparian zones and paperbarks
- Escarpment country
- Jungles

- Invasive species (weeds and ferals)
- Climate Change
- Ranger Mine site rehabilitation
- Fauna (focusing on threatened species), and
- Marine/mangroves and the intertidal zone.

Presenters were provided with a number of focus questions and issues including:

- Summarise the current knowledge in relation to those KNP management objectives as outlined in the current Plan of Management with a view of bringing in new and recent findings;
- What are the main threats to landscape health in KNP;
- How should the Park manage these threats to maintain and/or restore a resilient and healthy landscape in KNP; and
- What information is still required to develop effective land management policy? ie what are the key knowledge gaps.

Workshops addressed the following focus questions and issues:

- Consider the issues, questions and recommendations posed by presenters;
- Review how threats are currently being managed and at what cost (environmentally and budgetary) and make any suggestions for improvement;
- Identify what questions managers and traditional owners want answered to help guide future research and management?; and
- Identify what information is still required to develop effective land management policy? ie what are the **key** knowledge gaps.

Structure of this report

The report structure follows the order of proceedings of the workshop. The workshop comprised a series of powerpoint presentations, with questions and discussion during and after each presentation. Each presenter(s)/author(s) provided a written focus summary and a short paper addressing the issues outlined above. These summaries and papers are presented here in the same sequence as at the workshop and contain material additional to that of the powerpoint presentations. Some authors provided references (further reading) in addition to those included in their papers and these have been included in the bibliography after the paper where applicable.

2 Landscape change overview

JCZ Woinarski[1]

2.1 Focus summary

2.1.1 Current knowledge

Change is a fundamental quality of all things; and dynamism is a feature of most environments in Kakadu National Park. Some environments – notably the stone country – are exceptional, in maintaining an unbroken history in the landscape extending over 100 million years. In contrast, the lowlands are characterised by a chaotic history driven by climate variability and sea-level changes. One notable feature is the emergence of broad coastal floodplains from extensive mangrove forests from 10–5000 years ago.

Landscape change has contributed to the loss and gain of species in Kakadu.

Landscape change in KNP is being documented with increasing resolution, through a combination of newly available technologies, monitoring, and personal accounts.

Notwithstanding the 'natural background' levels of landscape change, modern processes have ratcheted up the pace of change, and forced environments into novel states and an uncertain and unprecedented future. The most important of these new pressures are global climate change and enhanced levels of atmospheric CO_2, impacts of introduced plant and animals, and substantially altered land use and management over the last 50 or so years.

2.1.2 Main threats

- (largely) uncontrollable extrinsic factors (notably global climate change (including increased intensity of cyclones, increased fire intensity, changed temperatures & rainfall regimes, sea-level rises, changed scope for international migratory species, increased population pressures);
- fire regimes;
- exotic plants and animals;
- lack of explicit valuation of Kakadu's natural resources;
- lack of knowledge of factors forcing change, susceptibility/robustness to change of environmental elements, and capability to direct or manage change;
- residue of historic land-use changes.

2.1.3 How should the Park manage these threats?

- through a coordinated research and monitoring program, aimed at determining what elements are changing, what are static, and what are most susceptible;

[1] Biodiversity Conservation Division, Dept. of Natural Resources, Environment and the Arts, Darwin, PO Box 496, Palmerston, NT 0831.

- through a research program that establishes the causes of change, and how (or if) these causal agents can be controlled or mediated;
- through an assessment of the value of environmental attributes and states. What is important to keep, to manage or to fight for;
- as a consequence, through cost-effective choices of directional management, tied to monitoring that assesses their efficacy in meeting their aims.

2.1.4 Key knowledge gaps

- climate change projections are imprecise and not locally explicit;
- uncertainties about how species and environments will respond to climate change;
- notably little information on trends for most threatened species (due to lack of specific monitoring programs, or broad-brush monitoring generally), and the factors causing such trends;
- only vague assertions about what Kakadu values are pre-eminent;
- limited assessment of cost-effectiveness and efficacy of management options.

2.2 Paper

2.2.1 Introduction

All things change. Sometimes the change is imperceptibly slow; sometimes bewilderingly fast. Sometimes it is desirable for us; sometimes not. Sometimes change may happen in ways that we can control; sometimes not. Sometimes change may be predictable; sometimes not. Some of us like change; others like the familiar.

It is through change that we have the world that we now know. Change is the building block of evolution – of species and landscapes and culture.

Kakadu is a dynamic land, with change driven by global and local influences. A major shaker of the system was the rapid global sea level rise from about 20 000 to 8 000 years ago (Fig 1), which drastically altered the coastline and must have forced major realignments of clan boundaries, and redefined coastal wetland systems. Much of the floodplain was vast mangrove forest until relatively recently.

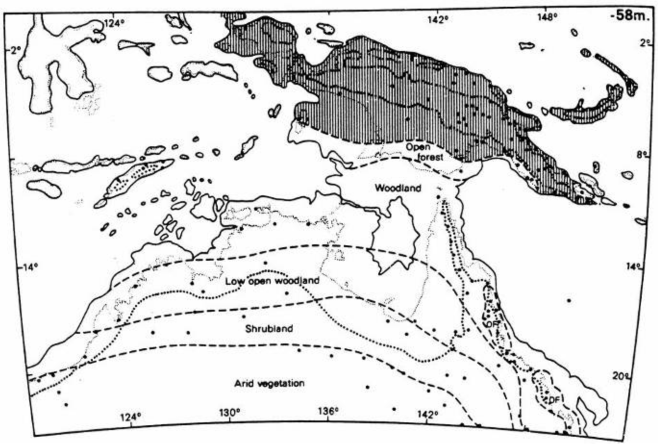

Figure 1 Land-sea boundaries about 12 000 years ago, showing the distribution of broad vegetation types (from Nix & Kalma 1972)

In part some exception to the turbulent history of the Kakadu lowlands, the stone country has existed unbroken in this landscape for at least 100 million years, quarantining its biota from the chaos below. Such shelter has allowed the persistence of relicts from a far earlier age (such as the tree *Podocarpus grayii*), the development of high levels of endemism and the local speciation of some highly restricted species-groups.

The dominant animal species – the megafauna – were lost from the Kakadu systems sometime over the period from about 40 000 to 5000 years ago; rock art and fossils mark the memory of the creatures that once probably adorned and moulded the landscape.

As with all Australian environments, but perhaps especially so (given the richness of the environments and consequent high human population density), the Kakadu landscapes were also tuned by the management of Aboriginal people for millennia, to the extent that the biological elements existed in some managed equilibrium.

Over the last 100 years, that equilibrium has been disrupted by the consequences of European settlement, to the severe disadvantage of some elements. The land was usurped or put to use by pastoralists and by miners. The settlers deliberately introduced to the Kakadu lands buffalo and cattle, horses, gamba grass and mission grass. Pigs, cane toads, honey bees, exotic ants, new diseases, cats, salvinia and many others came on the tide of European settlement. About 100 foreign plant species (about 5% of the Park's flora) now occur wild in Kakadu (Brennan 1996) and foreign animal species are amongst the most abundant of all vertebrate animals in Kakadu. Each such foreign species will have some impact on the native species; and for some foreign species that impact may be catastrophic.

The management pattern of Kakadu has been severely disrupted as traditional owners were removed or left country, as pastoralists and buffalo hunters sought to impose new management regimes, and as knowledge was lost and the lands and their resources used to different purpose. Some consequences of such management change are obvious – the widespread loss of *Callitris* pines being one such case – but others may be more subtle and/or take longer to become apparent. We will live for many years with the legacy of previous mismanagement.

The Kakadu landscapes are also affected by more global factors. The marked increase in atmospheric carbon has affected vegetation dynamics world-wide, and has probably contributed to an increase in woody vegetation across much of northern Australia. Global climate change will cause sea-level rise, with plausible loss of Kakadu's most productive systems, the rich floodplain wetlands to saltwater intrusion. It may also cause an increase in the incidence of high intensity tropical cyclones, with potentially devastating consequences for Kakadu's environments and infrastructure.

This complex cocktail of factors is now driving change to the Kakadu environments that is probably unprecedented in pace and extent.

2.2.2 Kakadu's role

It is easy to consider Kakadu in isolation, to think only of the changes that affect it, and how these changes can or should be managed. But there is a broader context that should also be considered. Increasingly, the lands to the west and south of Kakadu are being transformed to harness their perceived agricultural value. Much of that external landscape is not managed for biodiversity conservation, and so an increasing proportion of the biodiversity of northern Australia will be reliant upon Kakadu. And there are few areas in the world where such a large natural system can be maintained: smaller and more poorly resourced parks will be far less resilient to change.

2.2.3 Managing change

Kakadu's landscapes are changing. How should such change be managed? This is a difficult question that may take many years to resolve. The following framework may help.

1. ***Recognise change.*** It is futile to pretend that the Kakadu landscapes and the plants and animals within them will remain static over our lifetime. We need to document what is changing and what is stable. This requires systematic inventory and monitoring, in some cases from direct fieldwork and in others through imagery.

2. ***Understand change.*** To manage change, we need to know what are the drivers of that change, the rate and pathway of change, and the extent to which it may be reversible or controllable.

3. ***Define the values and attributes that we want to maintain.*** Inevitably, we value some things more than others and we may have to strive harder to protect from detrimental change some species than others. In part, the most significant natural values are specified through legislation (eg species listed as threatened under the *Environment Protection and Biodiversity Conservation Act*), through the assets that contributed explicitly to World Heritage qualification, through cultural significance, and through context (the values that can be protected within Kakadu but not elsewhere). Largely from such bases, we need to specify what it is that we want in Kakadu over a long timeframe.

4. ***Use management to corral change to the desired outcomes.*** Some change may be beyond our capacity to manage; but other factors causing change may be controllable or capable of some guidance. We need to understand what management regimes work to inhibit or direct change to the landscape states that we want. Amongst the various management options that are available, we need to evaluate which ones are most cost-effective and enduring.

5. ***Monitor that management effectiveness.***

6. ***Embrace change.*** Kakadu landscapes may be changed by some factors that we cannot control. If all else fails, we should be prepared for such inexorable change, and accept the new.

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3 Ecological risk assessment

P Bayliss[1]

3.1 Introduction

These notes provide some background to ***eriss***'s Ecological Risk Assessment program for the Magela floodplain, downstream of Ranger uranium mine. This program deals with both point source mining and diffuse non-mining risks to Kakadu values at the landscape scale (ie multiple threats to multiple assets at multiple scales). The background notes are taken from the Supervising Scientist Division web page on Ecological Risk Assessment compiled by James Boyden of ***eriss***. These notes accompany the presentation by Peter Bayliss titled: 'Using a risk assessment approach to manage landscape change', which walked the audience through the eight basic steps in undertaking any risk assessment (Figure 1). The fact that successful ecological risk assessments need to be underpinned by effective stakeholder engagement and input from the outset was highlighted throughout the talk.

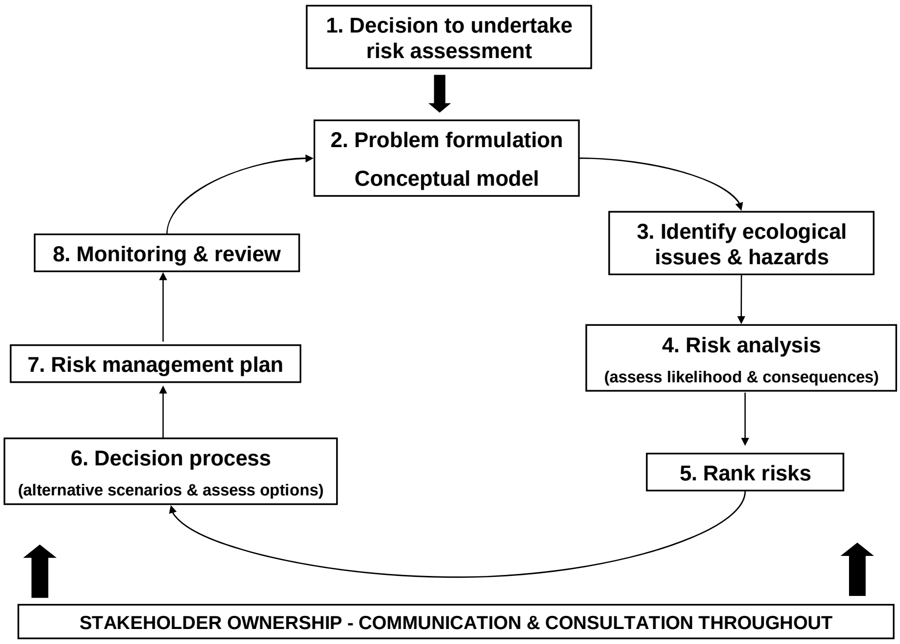

Figure 1 Risk assessment framework and the eight basic steps in the process (see presentation) which is underpinned by effective stakeholder engagement and ownership

Natural resource managers in the Alligator Rivers Region (ARR), and elsewhere in northern Australia, have few tools to determine what environmental assets are at greatest risk from multiple threats, whereby threats can range in scale from point source pollutants, to diffuse landscape-scale impacts of say invasive species and unmanaged fire, through to the potential impacts of climate change on regional and global scales. Ecological Risk Assessment is a powerful analytical tool that allows objective comparison of the relative risk contributed by each specific 'threat' to ecological structures being managed. This permits risks from multiple

[1] Environmental Research Institute of the Supervising Scientist, GPO Box 461 Darwin NT 0801

stressors to be evaluated and communicated in a logical, robust and transparent manner. The process therefore facilitates optimum decision making for the management of natural resources through complete use of available information on potential environmental stressors, and through participative consultation with all stakeholders.

Kakadu National Park has Ramsar-listed wetlands and is a World Heritage site, but the mining and milling of uranium has occurred on a mineral lease within its boundaries for 25 years without any major off-site environmental impact. Nevertheless, Kakadu is exposed to other major ecological threats such as invasive species and climate change. For the past five years ***eriss*** has been undertaking a quantitative ecological risk assessment of the Magela Creek floodplain, downstream of Ranger mine that encompasses threats identified from:

- point source mining-related risks; and
- diffuse landscape-scale risks.

A high protection level for the biodiversity of aquatic ecosystems was used as the assessment endpoint and, whilst measurement endpoints inevitably varied, they all encapsulate some metric of 'species affected' facilitating comparison between different risks. For minesite risks the focus was on three key chemicals (uranium, sulfate & magnesium) in the surface water pathway, and the focus for landscape-scale risks was wetland weeds, feral pig damage and unmanaged fire.

Additionally as part of the Tropical Rivers Inventory and Assessment Project, ***eriss*** is undertaking a broad-scale ecological risk assessment of key threats to Australia's tropical rivers.

3.2 The 'ecological risk assessment' process

'Ecological risk assessment' is the term ascribed to the method(s) for determining risk posed by a stressor (contaminant or perceived threat) to the survival and health of ecosystems. Under these procedures ***risk*** is defined as the probability that an adverse effect will occur as a result of ecosystem exposure to a particular 'concentration' of the stressor. Hence ***risk*** is determined by measuring two components:

- the ***consequences*** (also measured as effects)of an adverse event; and
- the ***likelihood*** or *probability* of the event occurring (exposure).

Using these criteria, risk is quantified as the probability of an adverse event, or the likelihood of exposure multiplied by the consequences or effects of that exposure (Prisk = Pexposure x Peffects).

Hence, the aim of ecological risk assessment is to estimate the probability of adverse events from identified environmental stressors. Traditionally, ecological risk assessment has been used to investigate the effects of the release of particular chemical pollutants (toxicants) into the receiving 'environment'. However, ecological risk assessment is now applied more broadly to assess the relative impact potential of multiple 'threats' against measured and/or predicted impacts on environmental values (appropriate & measurable monitoring endpoints).

The systematic steps for performing ecological risk assessment, as applied to an identified stressor, are outlined in Figure 2. Here it is important to emphasise the iterative nature of risk assessment in that results are updated periodically based on inclusion of new data and/or monitoring information. Further, risk-reduction strategies are developed from improved understanding of both the risks posed by specific stressors and of the processes contributing to them. In this context ecological risk assessment plays an important role in best-practice natural resource management based on adaptive management principles.

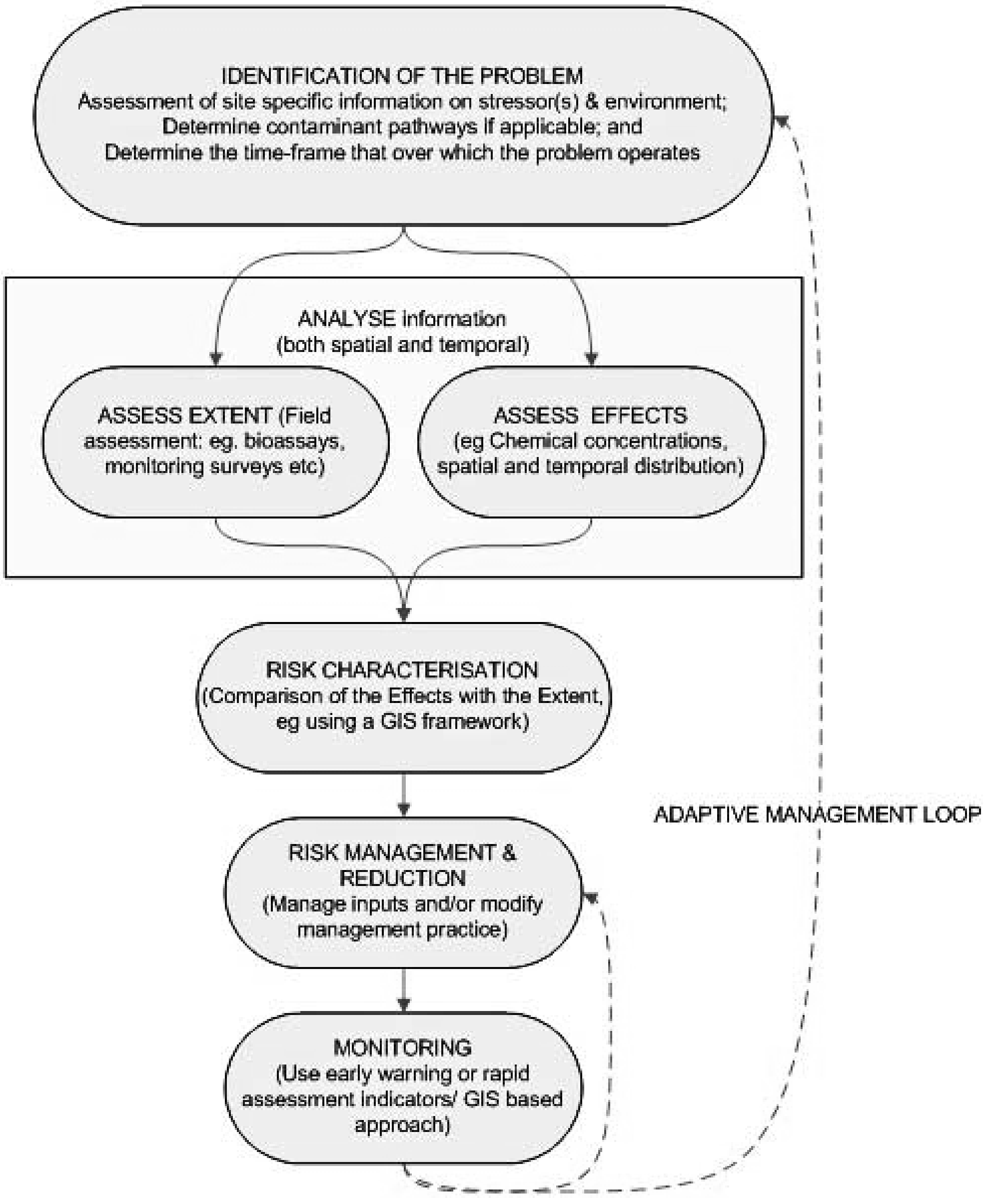

Figure 2 A basic framework for conducting ecological risk assessment (adapted from US EPA1998)

Consider the example of determining the risk of exposure to toxic levels of uranium to biota in Magela Creek waters downstream of Ranger mine. In this case there are two information sources for the assessment:

- *Exposure* observations from monitoring records of uranium concentration in Magela Ck (eg Figure 3, left hand curve); and
- *Effects* observations, where the No-Observed-Effect-Concentration (NOEC) thresholds are measured for six native aquatic species of Magela Ck using ecotoxicity testing procedures (Figure 3 right hand curve).

Figure 3 highlights the fact that uranium levels for all *exposure* observations fall well under the *effect* thresholds and, hence, the risk probability for exposure to uranium at detrimental levels in Magela Ck is for all practical purposes close to zero.

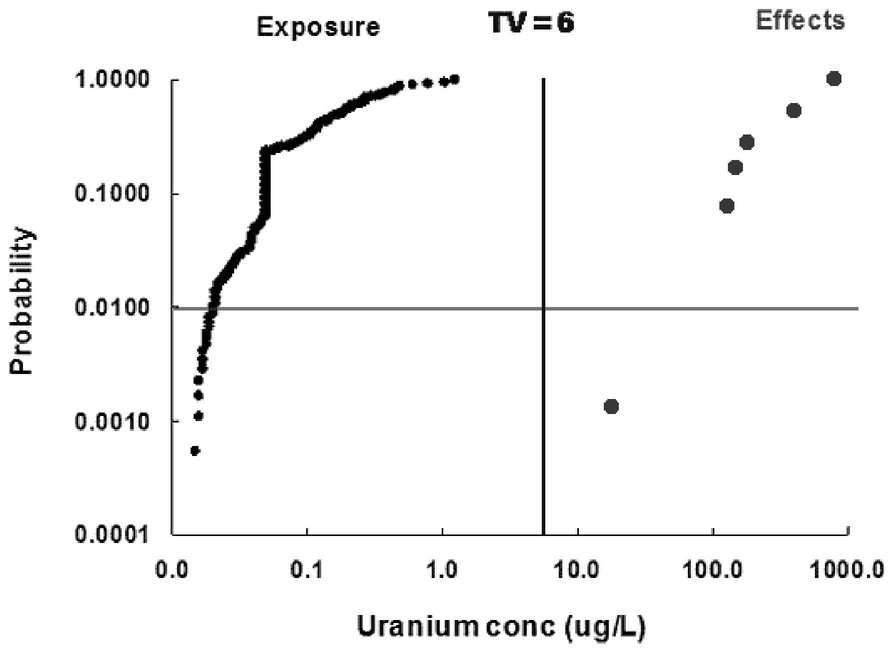

Figure 3 Cumulative probability for *exposure* to uranium in Magela Ck, downstream of Ranger mine (1998–2005) and for potential *effects* (No-Observed-Effect-Concentration) of uranium on six native aquatic species, and was derived from ecotoxicological studies. TV = monitoring trigger value for uranium in Magela Ck whereby 1% of species are predicted to be affected at uranium concentrations >= 6 µg/L.

A high level of protection for aquatic biodiversity conservation values comprise the *assessment endpoint.* Uranium concentration exposure data is obtained from a water quality monitoring program undertaken when effluents from Ranger are discharged into Magela Creek during wet season flow periods. Exposure data are combined with ecotox-derived trigger values (TVs) for uranium concentration (effects data), whereby 1% or more of species are affected (ie >= 6 µg/L). The TV provides a practical *measurement* endpoint that combines both exposure and effects data, and is basically the risk assessment itself.

While risks of hazardous exposure to uranium (and other mine-related products) have been found to be extremely low in Magela Creek, a risk-reduction strategy is nevertheless in place. Objectives for water quality management are based on minimum dilution requirements for mine-related products in receiving waters of Magela Creek. The uranium limit of 6 µg/L recommended by the Supervising Scientist has been derived using local ecotoxicological data in accordance with the Australian Water Quality Guidelines to protect 99% of the species present. In the event that a limit is exceeded, an agreed and practical management response is identified. In this case, therefore, risk-reduction management is intrinsically linked with the regulation and controlled release of mine waste-waters, offsite. When used in conjunction with timely monitoring information, these guidelines provide the basis for the ongoing management and re-evaluation of risks to Magela Creek biota.

Depending on the information available for undertaking ERA, there are several approaches used to characterise risk. The classical quantitative approach, based on frequency information for effects and exposure, uses null hypothesis testing and likelihood estimation. Where frequency data are not available a Bayesian statistical approach that involves assessing different 'degrees of belief' using qualitative or semi-quantitative reasoning is often used. In practice, a combination of techniques are used, where semi-quantitative assessments tend to be precursors to quantitative assessment (Figure 4). For example, conceptualising risk pathways to identify how and what risks may arise and to plan targeted monitoring is an important qualitative step from which quantitative data can then be acquired. Alternatively, applying a structured semi-quantitative approach to ranking risks (eg Table 1), which considers uncertainties, is a beneficial way of determining priorities, particularly when assessing risks from multiple stressors. This is often done using an expert technical panel to review available information.

Table 1 Risk matrix of consequences vs likelihood (adapted from AS/NZS 1999)

	Consequences				
Likelihood	**Insignificant 1**	**Minor 2**	**Moderate 3**	**Major 3**	**Unknown 4**
A (Almost certain)	**H**	**H**	**VH**	**VH**	**U (H)**
B (Likely)	**M**	**H**	**H**	**VH**	**U (M)**
C (Possible)	**L**	**M**	**H**	**VH**	**U (L)**
D (Unlikely)	**L**	**L**	**M**	**H**	**U (L)**
E (Unknown)	**U (L)**	**U (L)**	**U (M)**	**U (H)**	**U**

VH= Very High; H-High; M=Medium; L=Low; U=Unknown

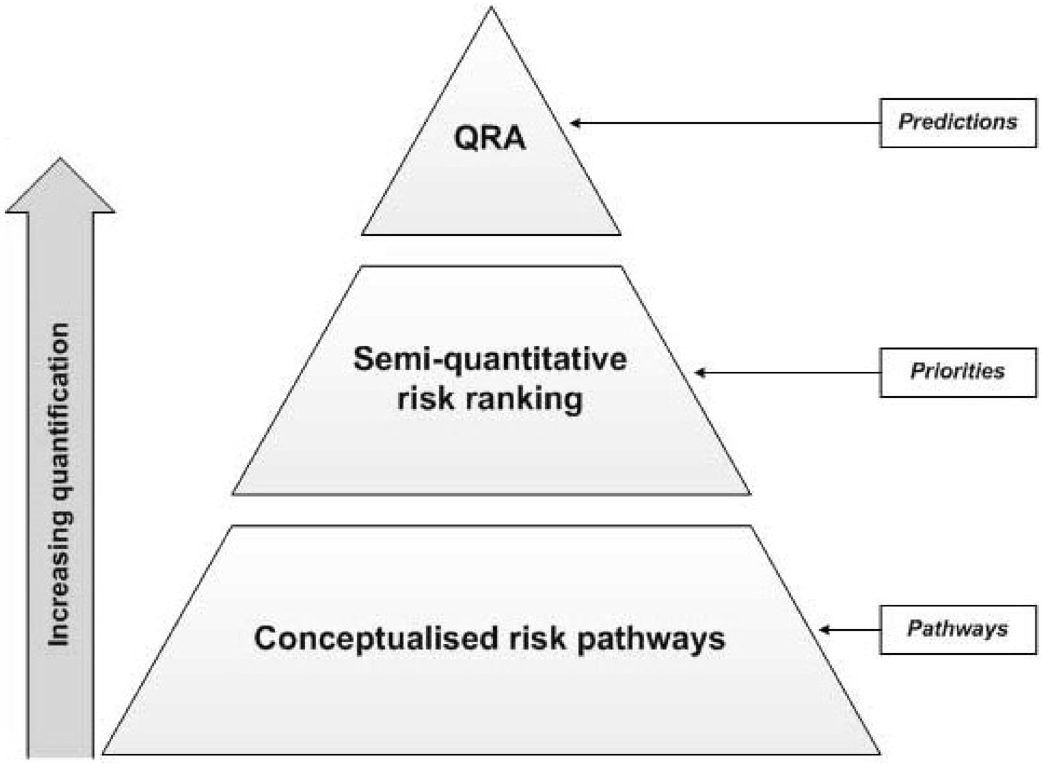

Figure 4 The different levels of risk assessment (after Deere & Davidson 2005)

3.3 Ecological risk assessment at the landscape-scale in the ARR

The International Science Panel (ISP) in its 2000 examination of whether the Kakadu World Heritage status was at risk from impacts of uranium mining, recommended landscape and ecosystem analyses and called for a comprehensive risk assessment within the context of the Kakadu World Heritage area.

Maintenance of the natural World Heritage Values of Kakadu National Park (KNP), as they pertain to pressure from mining-related activities, underpins the landscape analyses undertaken by ***eriss***. To ensure the protection of the region from the effects of uranium mining, and to encourage best practice in ecosystem management and conservation it is important that managers and regulators understand the relative importance of all potential 'threats' to World Heritage values.

Environments of the region are subject to change from multiple threats that operate over differing spatial and temporal scales. All have some potential to diminish World Heritage values. Exotic feral animals and weeds, and the potential for landscape level change induced by climate change and subsequent sea level rise and altered fire regimes are considered among the more serious threats to these values. Uranium mining activity poses but one point-source for contaminants that can potentially enter the surrounding environment of KNP.

The aim of this program is to broaden the contaminants risk assessment of Ranger mine to include key non-mining stressors at the landscape-scale, thereby placing contaminant issues for Ranger mine within an integrated risk assessment framework. The initial assessment focused on threats to world heritage values of the Magela floodplain (eg measured damage to natural habitats) and incorporates quantitative information on risks from both mining and non-mining threats (Figure 5). A secondary aim is that this risk assessment model be developed for use as a decision support tool for assessing and managing multiple ecological risks at multiple scales.

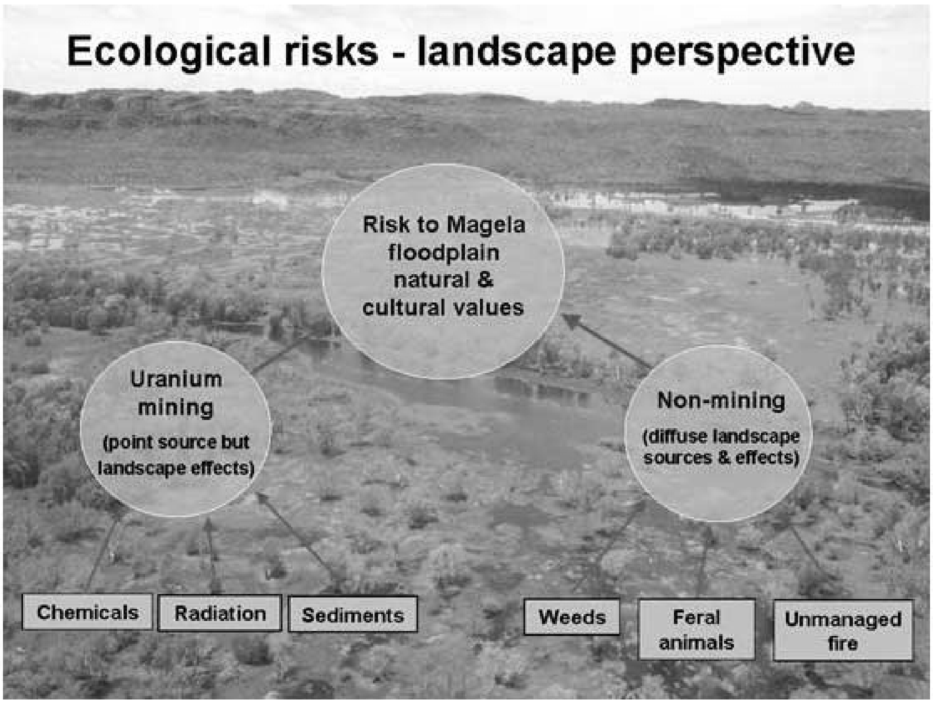

Figure 5 Outline of the landscape-scale risk assessment for the Magela Creek floodplain, Kakadu National Park

Initial results from the risk assessment are summarised in Table 2 and are elaborated in more detail in Section 3.10 of the Supervising Scientist Annual Report 2005–2006. Two key results from the integrated assessment are:

- Non-mining landscape-scale risks are currently several orders of magnitude greater than mining risks (Table 2), although that difference may reduce when on-site water management systems at Ranger mine change in the transition between mine production and mine closure and rehabilitation; and

- Para grass weed (*Urochloa mutica*) is currently the major ecological risk on the Magela floodplain because of its extent (10% cover), effect (a monoculture that displaces native vegetation and wildlife habitat) and rapid spread rate (14% per annum). Note the risk posed by para grass has been examined in greater detail by combining a Bayesian habitat suitability model with a spread rate model, therefore encompassing current and future risk to floodplain habitat diversity depending on distance to source and invasion pathways.

Table 2 Comparison of landscape and minesite ecological risks to the Magela floodplain, and their relative importance rank

Category	Pathway	Hazard	Risk rank	Action	Time frame
Landscape	Floodplains	Para grass weed	1	Active control	In perpetuity
	Park-wide	Pig damage	2	Research effects	In perpetuity
	Floodplains	Unmanaged fire	3	Research effects	In perpetuity
		Total ecological risk prob =	0.21		
Minesite	Surface water Magela Ck	Uranium	4	Watching brief	2020
		Sulfate	5	Watching brief	2020
		Magnesium	6	Watching brief	2020
		Manganese	7	Watching brief	2020
		Total ecological risk prob =	0.00009		

The overall findings from the landscape ecological risk assessment suggest that non-mining landscape-scale risks to Magela floodplain should from now on receive the same level of scrutiny as applied to uranium mining risks, including an assessment of what appropriate level of investment would be needed to manage these risks. The ultimate challenge however, is linking the costs of reduction in ecosystem health ‘damage’ to perceptions of socio-economic and cultural benefits in order to optimise management investments under budgetary constraints. At the end of the day decision support tools need to be realistic, pragmatic, defensible and provide management options that at least balance costs and benefits.

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4 Savanna dynamics

C Lehmann[1] & L Prior[1]

4.1 Focus summary

- Describes cover change that has occurred in KNP savannas;
- Focus is on fire as a key influence on savanna tree cover;
- Makes the point that no single fire regime is ideal; need variety in space and time, including several consecutive years without fire at various locations to allow young trees to escape the fire zone;
- Gives the decline of cypress pine as an indication that in many savanna areas we are not replicating traditional Aboriginal landscape burning;
- Ground layer vegetation (especially grass) is an important component of savanna vegetation, which probably has large effects on the fauna. We don't know as much about this vegetation as we do about trees;
- We do know that frequent fire encourages growth of speargrass (*Sarga*, previously known as *Sorghum*), which is highly flammable. Land managers may be locked into burning areas with extensive speargrass early each dry season, which further encourages its growth. In KNP and other places, wet season burning is used to break this cycle;
- Other threats will be covered in other sessions of the symposium; they include introduced African grasses, feral animals, and possibly climate change and increasing atmospheric CO_2 concentrations.

4.2 Paper

4.2.1 Introduction

Savannas are defined as areas with a continuous grass layer, more or less interrupted by trees and shrubs (Johnson & Tothill 1985). Savannas are the characteristic vegetation of the seasonal tropics, and cover about 1/3 of continental Australia. Savannas in wetter regions such as Kakadu National Park have the potential to become dry tropical forests with closed canopies. However, these areas are generally maintained as savannas by regular dry season fires, which kill the stems of many young trees while having little effect on the grasses. Thus while rainfall sets the upper limit on the tree cover in the seasonal tropics, fire is a key influence on the actual vegetation found in an area (Sankaran et al 2005). Other important influences are herbivores and soil nutrients, which are themselves influenced by fire regime (Johnson & Tothill 1985).

There have been reports of increasing woody vegetation in savannas around the world, including Australia (Archer 2007). One suggested cause is increased grazing pressure, which reduces the amount of available fuel and can therefore decrease fire intensity and fire

[1] School for Environmental Research, Charles Darwin University, Darwin NT 0909

frequency. Alterations in fire regimes due to other changes in land management may also be responsible. Fluctuations in climate (whether natural, or resulting from global warming) may also cause changes in tree cover. Another important possibility is the increasing carbon-dioxide (CO_2) concentration in the atmosphere. This is because woody plants and tropical grasses have different photosynthetic pathways, and the increased CO_2 gives a bigger advantage to woody plants than it gives to the grasses, and the resulting increased growth rates are relatively higher for woody plants (Ainsworth & Rogers 2007).

While tree cover may be increasing in some savanna areas, there is also concern that changes to fire regimes may be causing a gradual decline in tree cover in other areas. Some older studies (Russell-Smith et al 2003, Prior et al 2006) in parts of Kakadu found there were very few or no trees in the mid-storey (approx 0–5 cm dbh range), raising questions about whether older trees would be replaced after they died, or if the savannas would gradually thin to grassland. Large-scale studies were needed to show whether tree cover in Kakadu has increased or decreased over the last 40 years.

4.2.2 Changes in tree cover in Kakadu National Park

Because savannas are typically very dynamic ecosystems, it can be difficult to detect long-term, regional trends in tree cover from background 'noise'. Historical aerial photography offers perhaps the only practical way of quantifying changes in tree cover, and testing whether there are long-term trends in any direction.

A recent study (Lehmann, Prior & Bowman, submitted) has shown large and locally variable changes in tree cover at 50 sites in Kakadu's stringybark (*Eucalyptus tetrodonta*) savannas over the last 40 years, with an overall small increase in tree cover from 63 to 68 % (Figure 1). This study showed that the increase in tree cover was larger at sites that were burnt less often. The study also showed that there was more fire, and wider fluctuations in tree cover, in the north of Kakadu than in the south.

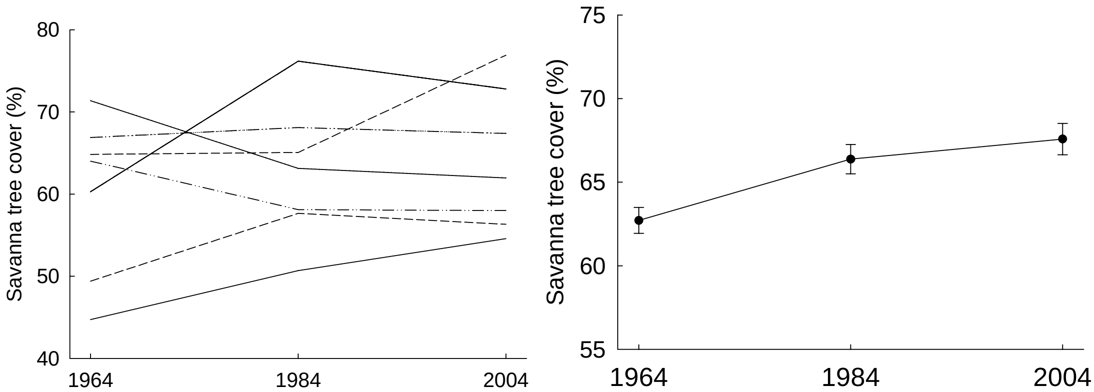

Figure 1 Tree cover change over 40 years in stringybark savanna in Kakadu National Park. The left hand graph shows examples of change at individual sites, and how variable this can be, while the overall change in cover averaged over 50 sites is shown in the right hand graph. Figure based on Lehmann, Prior & Bowman (submitted).

4.2.3 What effect does fire have on savanna trees?

Most savanna tree species are well adapted to fire – for example, most resprout readily from below ground, and saplings tend to grow tall and thin, to escape the fire zone as quickly as possible. Even so, recruitment, growth and survival of savanna trees are all affected by fire, especially when it is very intense or very frequent.

In the Kapalga fire experiment, which ran from 1990 to 1995, some plots were not burnt at all, some were burnt annually in the early dry season, and others were burnt annually in the late dry season. In the final year, an intense wildfire burnt two of the previously unburnt plots. Annual late fires and a single intense fire had an especially severe effect on stem survival and tree growth, but growth of juvenile trees (<1.5 m high) was most affected by early dry season fires (Figures 2 & 3). There were many more recruits to the > 3 m height class in unburnt plots than in those burnt annually in either the early or late dry season, and no recruits at all following the intense wildfire (Dick Williams, unpublished data).

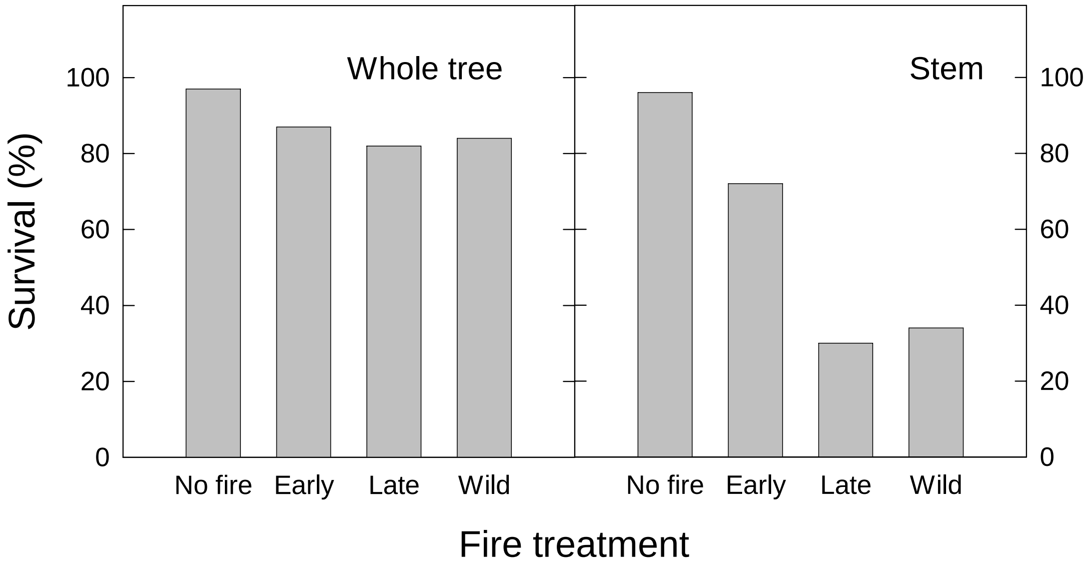

Figure 2 Whole tree survival was generally high following fire, but survival of individual stems was much lower, especially for late fire and the intense wildfire (based on Williams, Cook, Gill & Moore 1999)

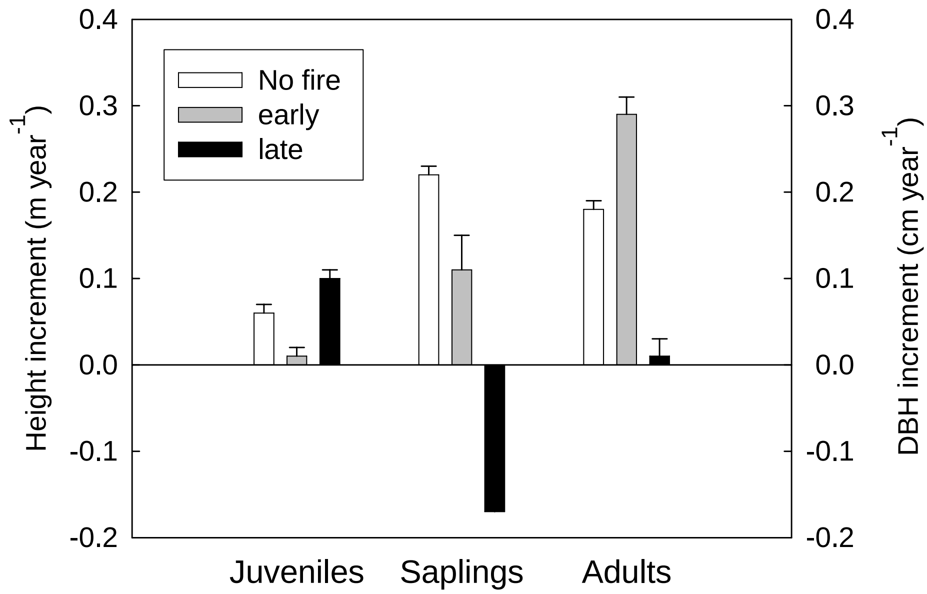

Figure 3 Effects of the three fire treatments on annual height growth of juveniles (<1.5 m high) and dbh (diameter at breast height) growth of saplings (> 1.5 m high and < 5 cm dbh) and adults (> 5 cm dbh). The effects were complex, and varied for different size classes of trees (from Prior, Brook, Williams, Werner, Bradshaw & Bowman 2006).

It would not be desirable to implement any one of these fire regimes year after year, even if it were possible, because they all disadvantage certain size classes of tree. Instead, it is better to have a mix of fires of different sizes and in different seasons. It is especially important for particular areas to have several consecutive years without fire, to allow new trees to grow into the adult size classes. Researchers are planning to model how frequent and how long these fire-free intervals need to be to maintain healthy stands of savanna trees.

Although most savanna tree species are fire-tolerant, and can persist through a wide range of fire regimes, there is a notable exception – cypress pine (*Callitris intratropica*). This species has been declining over much of its former range in northern Australia, and is now most frequently found in fire-protected areas such as gorges and rocky ridges. Whereas large trees can survive mild fires, seedlings cannot (see Figure 1). Modelling showed that mild fires every 2–8 years are required to maintain healthy populations of cypress pine (Price & Bowman 1994). This species is therefore a powerful bio-indicator of altered fire regimes. Its decline serves to warn us that our land management is not reproducing the traditional Aboriginal landscape burning that allowed cypress pine to thrive across extensive areas of savanna in northern Australia.

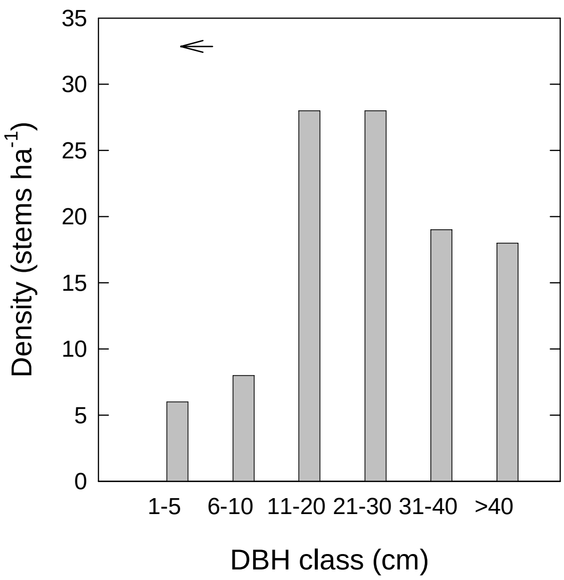

Figure 4 Stand structure of a cypress pine population adjacent to Round Jungle, Kakadu in 2005. The arrow shows the number of 'small' trees (< 5 cm dbh) required to maintain a stable population – far more than were actually present. (Redrawn from Prior, Bowman & Brook 2006)

4.2.4 Grasses and groundlayer vegetation

There has been much less research focus on groundlayer vegetation than on trees, but the groundlayer is important in its own right, for providing shelter and food to animals, and it also has a critical role as a fuel source.

Very frequent fires may lead to the dominance of a small number of annual grass species such as *Sarga* (also known as *Sorghum* or speargrass) (Russell-Smith et al 2003). Indeed, some traditional owners regard the presence of dense *Sarga* as evidence of poor fire management (Yibarbuk et al 2001). *Sarga* is very flammable, so its presence can lock land managers into annual early dry season burning, which further advantages this grass. Perhaps the most practical way of breaking this fire cycle is by wet season burning, which kills the grass at a time when there is no seedbank.

More research is needed on the effects of fire on groundlayer vegetation, and flow-on effects on native fauna.

4.2.5 Other threats to Kakadu's savannas

1 Introduced grasses such as gamba grass and mission grass produce much higher fuel loads than native grasses, and cause much hotter fires. Whereas most savanna trees currently survive fire, this is not the case if there is a heavy infestation of these introduced grasses (Ferdinands et al 2006).

2 Feral animals, such as buffalo, may also cause problems, especially when they occur at high densities.

3 Climate change may lead to changes in rainfall patterns and more destructive cyclones.

4 Increasing atmospheric CO_2 may change the composition of savanna vegetation.

4.2.6 References

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5 Landscape change in floodplains

M Douglas[1], P Bayliss[2], P Christopherson[3], A Petty[4], L Traill[5] & K Ferdinands[6]

5.1 Introduction

When we consider landscape change, it is hard to imagine a more dynamic part of the Kakadu than the floodplains. These extensive systems of seasonal freshwater wetlands did not even exist just a few thousand years ago (Clark & Guppy 1988), so in geological terms the floodplains have undergone a great deal of change over a relatively short period. The floodplains are also one of the most dynamic parts of the landscape over much shorter time scales. From dry cracking clays during the dry season to vast, productive wetlands teeming with water plants, fish and birds in the wet, these systems experience dramatic changes of boom and bust driven by the seasonal cycle of water availability.

Kakadu's floodplains are some of the most well studied wetland systems in northern Australia. Concerns about the impacts of various threats including mining, feral animals (water buffalo and pigs) and weeds have resulted in a long history of research activity focused on the floodplains. There have been numerous reviews and some recent compendia summarising our knowledge of these systems (eg Hope et al 1985, Woodroffe et al 1989, Knighton et al 1992, Finlayson et al 1997, Heerdegen & Hill 1999, Finlayson 2005) so this paper will focus on some of the more recent studies that are relevant to the issue of landscape change on floodplains.

5.2 Major threats to landscape health

One of the first steps in developing a successful management plan for Kakadu's floodplains should be to define a healthy floodplain. Although science can advise on these decisions, they are largely social decisions, and naturally must involve the strong participation of Bininj. Do we want to maintain the status quo, with a minimum of weeds and feral animals? Do we want to replicate as closely as we can the floodplains of 100 years ago, when small bands lived nearly year round on the floodplains and continuously burnt small patches through the dry season? Do we accept sea level rise as inevitable and manage for a return to the 'time of the mangroves' some 6000 years ago? These decisions will guide what management practices are implemented.

The processes that threaten the present state of Kakadu's floodplains also affect other parts of landscape and are discussed in other sections of this report: Climate change (Bartolo et al 2007, this volume), feral animals (Bradshaw 2007, this volume), weeds (Walden & Gardener

[1] Tropical Rivers and Coastal Knowledge Research Hub, Charles Darwin University, Darwin, NT.
[2] Environmental Research Institute of the Supervising Scientist, PO Box 461 Darwin Nt 0801.
[3] Australian Commonwealth Scientific and Research Organisation, Berrimah, NT.
[4] Tropical Savannas Cooperative Research Centre, Charles Darwin University, Darwin, NT 0909.
[5] Research Institute for Climate Change and Sustainability, University of Adelaide, Adelaide, SA.
[6] Weed Management Branch, Department of Natural Resources, Environment & the Arts, Darwin, NT.

2007, this volume) and fire (Edwards et al 2007, this volume). However, floodplains are probably more vulnerable to these threats than other parts of the Park.

Over and above the seasonal pattern, recent studies of waterbirds (Bayliss et al 2007a, 2007b) have revealed longer-term cycles spanning several decades. These cycles are indicated by several years of above average or below average wet seasons and these patterns of change are reflected in waterbird condition and abundance across the floodplains. These longer-term patterns will make it difficult to determine whether changes in the health of the floodplains are due to natural cycles or to human-induced changes, such as those described below.

For example, climate change probably poses the biggest threat to the present composition of the floodplains of northern Australia in the long term (approximately 50–100 years). Much of the floodplains lie so low that even modest sea-level rise will result in widespread salt water intrusion, and sea level rise will likely return them to a state some 6000 years ago when there were widespread mangrove swamps far inland of their present position (Woodroffe et al 1985). However, it is difficult to infer possible outcomes given that climate change will result in a shift in hydrological processes both from increased sea level and from changes in rainfall pattern (which are currently unknown). The loss of some inland wetlands may result in the creation of floodplains further inland. It is probably adequate to say that current floodplains that host vast waterfowl aggregations (Nourlangie Creek area) will experience shifts in the next 50 to 100 years, most likely to the detriment of some local waterfowl populations such as magpie geese. A more detailed discussion of the threat posed by climate change and consequent saltwater intrusion is given in Bartolo et al (2007, this volume).

Feral animals continue to pose a major threat to the floodplains of Kakadu. The effects of the water buffalo have been well documented in the Park, but active culling during the 1980s has meant that they no longer pose a threat. Recent evidence suggests also that their removal has aided plant regeneration and the stabilisation of saltwater channels on the floodplains (Petty et al 2005). However, the reduction in buffalo numbers has been accompanied by a dramatic increase in the density of feral pigs (Bayliss et al 2006) and the damage that they inflict on floodplains, although minor when compared with buffalo, has resulted in some concern about their impact. Recent studies have shown that feral pigs can seriously deplete the density of *Eleocharis dulcis* (Chinese water chestnut) bulbs but fortunately, they are usually only capable of extensive damage over a fairly small proportion of the floodplain (Traill 2008). The full effects of the recent spread of cane toads are not yet known but it has clearly led to dramatic reductions in animals such as floodplain goannas (see van Dam et al 2002) .

Floodplains seem to be particularly prone to weed invasion and several of Australia's worst weeds are found on the floodplains of Kakadu, but the Park also has an outstanding record of weed management. Two weeds of national significance are now largely contained (*Mimosa pigra*) or managed to minimise impacts on native plants and animal (*Salvinia molesta*). But the threats posed by exotic pasture grasses continue to increase; as does the body of research documenting its ecological impacts. Para grass (*Urochloa mutica*) is predicted to continue to spread across the Magela floodplain (Walden & Bayliss 2003) and will cause a range of negative impacts including the almost total displacement of the native vegetation (Douglas et al 2002, Bayliss et al 2006). Hotter fires from para grass may threaten native fauna such as turtles. In addition to the continued spread of this well-established species there are an increasing number of new occurrences of Olive Hymenachne (*Hymenachne amplexicaulis*) in the Park, another grass that displaces native vegetation. It is likely that new outbreaks of Olive Hymenachne will continue as it appears to be spread by waterbirds moving in from nearby catchments such and the Mary River.

Although the effects of fire on floodplains are less well understood than they are for other parts of the landscape (particularly the savanna), altered fire regimes are still considered an important threat to floodplain health. A number of factors are likely to have led to changes in the timing, intensity and/or frequency or fires on Kakadu's floodplains including increases in fuel load from the removal of buffalo (Petty et al 2007) and the spread of exotic grasses (Douglas & O'Connor 2004), and changes in the use of floodplains by Bininj. Recent studies over decadal time-scales (1985–2005) have shown that major changes in the timing and extent of fires across the landscape, including on floodplains, occurred in sympathy with trends in rainfall and ENSO. For example, there has been a decrease in the extent of late dry season fires and a corresponding increase in the extent of early dry season fires, over the past 20 years (Bayliss et al 2007c). Changes in dry season fire regimes on floodplains are likely to have altered the structure and composition of native vegetation. In particular woody plant cover on floodplains has increased with the concurrent removal of buffalo, change in fire regime and increased rainfall within the past two decades (Petty et al 2007).

The Boggy Plains fire study (Christopherson et al 2003) – an award winning collaborative research project combining Bininj knowledge and western science – has provided new information on the effects of fire management on floodplains. It has shown that it is possible to use fire regimes to achieve biodiversity and cultural management objectives for floodplains, including increased open water, plant diversity and abundance of waterbirds and turtles, and improved access to bush tucker. It also provided a mechanism for getting Bininj directly involved in floodplain fire management and research.

5.3 Management responses

The ability of the Park to manage these threats varies greatly. Climate change is driven by global factors beyond the Park's control whereas changes in fire regime can be dealt with almost entirely by modifying fire management within the Park. Feral animals and weeds need to be managed in conjunction with the Park's neighbours to prevent spread and reinvasion.

The Park needs to be aware of natural decadal cycles in climate and water availability and their influence on floodplain health. These natural trends need to be included in the interpretation of monitoring data so that they can be separated from responses to management actions in the Park.

Planning for the consequences of climate change for Kakadu's floodplains should be a high priority for Park management given their vulnerability to saltwater intrusion. People need to be better informed about the range of consequences, both negative impacts and potential benefits or opportunities, and Bininj need to have strong input into adaptation strategies. The dramatic changes and loss of floodplains may require radical response, such as the relocation of floodplain-dependant species to refuge habitats. It is important that Kakadu begin the process of monitoring plant cover and waterfowl abundances now, so that effective long-term strategies can be developed and implemented.

The management responses for feral animals and weeds are discussed in more detail in Bradshaw and Walden & Gardener (2007, this volume). However it seems clear that the Park urgently needs to make a decision on the management of exotic grasses on the floodplains. The continued spread of para grass, with fairly well-understood consequences, and the increasing threat of Olive Hymenachne, with even greater ecological impacts, needs to be addressed within a risk assessment framework. This would include an assessment of the likely impacts and the feasibility of control and would provide a more objective and transparent basis for future management.

The Park needs to develop a more comprehensive approach to floodplain fire management and this needs to include monitoring of floodplain health in response to fire management and, importantly, providing resources and facilitating Bininj involvement in the fire management of floodplains. Current approaches to floodplain fire management vary markedly between Districts, but the Park needs to adopt a co-ordinated floodplain fire plan that takes a Park-wide view of floodplain management.

5.4 Knowledge gaps

Many of the management responses mentioned above could not be fully implemented due to key gaps in our knowledge. Some key research needs include the following:

- Continued long-term monitoring of key indicators of floodplain health, including hydrology, weed and feral animal abundance, and fire and vegetation patterns. Previous long-term studies have already suggested a decadal cycle of change with respect to waterbirds, and this pattern needs to be tested for other water-dependent long-lived species such as some fish, amphibians and reptiles.
- More accurate predictions of the consequences of climate change at a scale appropriate to the Park are required to understand the impacts on floodplain and to underpin adaptation planning. The first priority should be the development of detailed hydrodynamic and hydrologic models based upon a high resolution (sub-metre) elevation model.
- Improved understanding of the impacts of fire on floodplains. We know that strategic use of fire can increase open water and plant diversity at a site, but we need to be able to predict the larger-scale and longer term outcomes of changes in fire management regimes. There is also a need to understand the effects of fire regimes on ecosystems processes such as nutrient cycling and carbon flow.
- Improved predictions of the rate of spread of wetland weeds. Some work on predicting habitats suitability and rates of spread of para grass has been undertaken on the Mary River and Magela floodplains, but little is known for Olive hymenachne. Comparative information on colonisation rate and habitat suitability is critical information for setting weed management priorities.
- Identification of the most effective methods to remove exotic grasses using fire and herbicide. There has been mixed success in attempts to control para grass and it appears that the rate and timing of herbicide application and the timing of floodplain inundation may all be important factors.
- Better understanding of floodplain regeneration following weed management. A study on Magela Creek observed rapid recovery of native vegetation following the removal of para grass (Douglas et al. 2002), whereas a study on the Mary River found very limited recovery (Penny Wurm pers comm).

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6 Riparian zones and paperbarks: Landscape change

A Petty[1], M Douglas[1] & K Ferdinands[2]

6.1 Focus summary

6.1.1 Current knowledge

Paperbarks forests (*Melaleuca* spp.) separate along a moisture gradient from infrequently wet paperbark swamps on clay soils to continually moist riparian forests on sandy stream banks. Riparian vegetation can be divided into two distinct types, riparian forest and adjacent seasonally-inundated savanna. Riparian forest, at least in Mary River District, can change rapidly but overall appears to be relatively stable. The seasonally-inundated savanna contains plant species similar to those growing next to small seasonal streams, and this vegetation has been found to be negatively impacted by late season fires. Bamboo forms homogeneous clumps that die off all at once, so may be a local driver of vegetation change.

6.1.2 Main threats

- Fire: although a natural process that contributes to the distinct forest/savanna boundary, too many late season fires can have a detrimental effect on savanna vegetation.
- Pigs: pigs appear to negatively impact seedlings and saplings. Seventeen out of 28 riparian sites visited in Kakadu showed signs of pig impact.
- Buffalo: although buffalo numbers are much lower than they were in the past, at their peak they had a profound impact on riparian vegetation. Continued buffalo population growth will negatively impact riparian vegetation.
- Weeds: riparian zones are major hosts for weeds. By far the greatest potential threat is para grass which supplants native vegetation and substantially increases fuel loads.

6.1.3 Management recommendations

- Feral animals, particularly pigs, are probably the greatest threat to riparian health, and a control program should be implemented.
- Fires in general are damaging to most riparian vegetation, particularly along small streams. However, early season fires are much less damaging to small streams than late season fires. In general, fires probably don’t reach larger creeks and rivers until later in the dry season. The current practice of breaking up country with early season fires is likely optimal for riparian vegetation.
- Continue to monitor the distribution of para grass and prevent its spread into major riparian systems and paperbark stands.

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1 Tropical Savannas Cooperative Research Centre, Charles Darwin University, Darwin, NT 0909.

2 Weed Management Branch, Department of Natural Resources, Environment & the Arts, Darwin, NT.

6.1.4 Knowledge gaps

- The level of threat from weeds, particularly para grass, on paperbark forests and riparian areas is virtually unknown.
- Recruitment patterns are very poorly understood for riparian areas. Riparian areas suffer frequent disturbance from floods and fire, and seedling recruitment is particularly challenging for riparian species. In particular the role of fire and flooding in shaping riparian communities and the impact of feral animals on recruitment warrant further study.
- Trends of change in riparian vegetation are presently unknown.

6.2 Paper

6.2.1 Introduction

Generally, 'riparian' refers to the vegetation that grows along river banks. However, riparian ecosystems are highly variable depending on the type of river. Further, because of the strong seasonality of Top End rainfall, even within one river the dry season flow will be very different from the wet season flow. For example, within the South Alligator River system, wet season flows vary from being contained within steep banks approximately twenty metres across within the South Alligator Valley near Gimbat, to a broad 'sheet' of water kilometres across flowing across the floodplains north of Yellow Water. By the end of the dry season perennial creeks still flow albeit at a much reduced level, whilst annual creeks are generally dry but may still contain patches of stagnant water as well as billabongs within a the creek bed.

With such variation, it might seem hard to capture what exactly makes a 'typical' riparian community – and, indeed, the types of plants that make up a riparian community do vary tremendously. However, we can define two general types of riparian vegetation (Figure 1). Paperbark forests are generally not considered riparian vegetation (unless they occur along a waterway) and make up a third vegetation class:

1. **Riparian forest:** Thick vegetation (usually 80 – 100% cover) growing directly around the main channel of flow (ie where is stays wettest the longest through the dry season. This vegetation is made up of a mix of paperbark species (usually weeping paperbark – *Melaleuca leucadendra* or angoldh – and silver-leafed paperbark – *Melaleuca argentea* or angurrgurr) and rainforest species. Along larger sections of riparian forests, vegetation will separate with the paperbark species occupying the lower bank near the river, and vines and other dry rainforest species occupying the upper reaches. These upper reaches also commonly have large stands of a bamboo species which is unique to the Top End and of great cultural importance to bininj– *Bambusa arnhemica* or bunjdi (Franklin & Bowman 2004).
2. **Seasonally inundated savanna:** Open savanna (usually 30–60% cover) with a mix of species, including ghost gums and bloodwoods (*Eucalyptus alba*, *Corymbia bella*, *Corymbia latifolia*, *Corymbia foelscheana*, *Corymbia polycarpa*, *Corymbia ptychocarpa*), ironwood (*Erythrophleum chlorostachys* or andubang) and red paperbark (*Lophostemon lactifluus* or anbuladan). As the name implies, this vegetation stays wet for a few weeks to a few months every year, and is completely dry in the dry season. It has species that can tolerate both inundation and drought.
3. **Paperbark forests** tend to grow along floodplain margins, depressions and other places that stay wet for a significant period of time. Stands are made up almost entirely of one to

a few species. Common species are broad leafed paperbark (*Melaleuca viridiflora* or andolh), weeping paperbark, *Melaleuca cajuputi*, and *Melaleuca dealbata* or anbarra.

Rivers are doubly significant for Kakadu. First, Kakadu was founded around three river catchments – the East, West and South Alligator Rivers. Secondly, rivers and creeks are ubiquitous – it's hard to go more than a few kilometres without coming across at least a small creek. They are a key part of the habitat mosaic that plants and animals rely upon to survive the fire, flood and drought characteristic of Kakadu. Ironically, rivers and riparian areas are not specifically mentioned in the management plan. However, they clearly are essential for maintaining biodiversity and landscape integrity within the Park (KNP Management Plan sections 5.6, 5.8), as a customary resource base of high aesthetic and cultural value for bininj (KNPMP sections 4.2, 4.3), and for tourist amenity and enjoyment (KNPMP section 6).

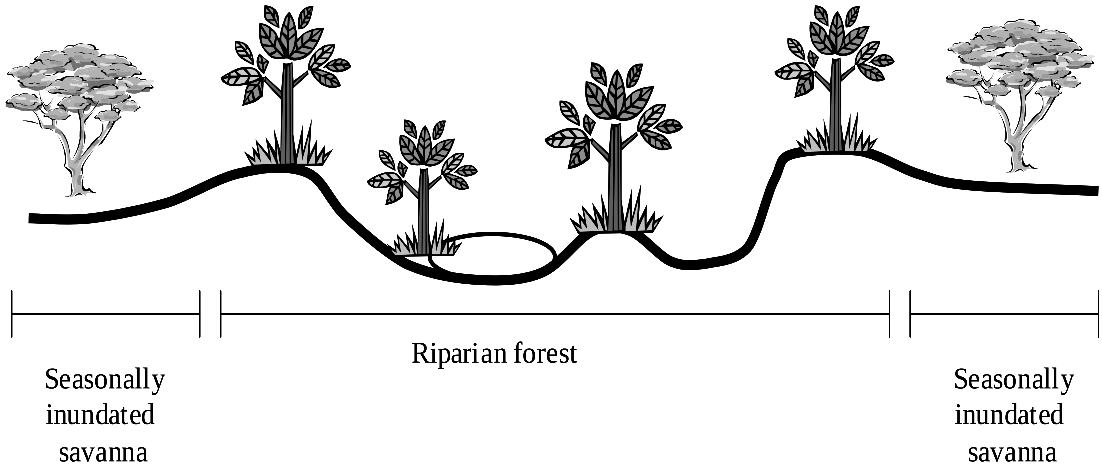

Figure 1 Diagram of plant community distribution in a riparian area

Riparian areas are equally important for bininj. They are used for food and recreation, and traditionally were major corridors for travel. Although the historical record is scant, there is little doubt that riparian areas were heavily utilised.

6.2.2 Paperbark (*Melaleuca* spp) patterns and processes

Paperbarks are the dominant element of riparian forests, as well as forming large stands along floodplain margins. Franklin et al (in press) argue that paperbarks predominate where a combination of flooding and other disturbances such as fire make life difficult for other species. All paperbark species are fairly tolerant of fire, but are separated into distinct communities by their ability to withstand flooding (Franklin et al in press).

The combination of fire and flood makes the structure of riparian forests particularly interesting. The most common species in riparian forests are silver-leafed (*M. argentea/*angurrgurr) and weeping (*M. leucadendra/*angoldh). This is probably because they are the most tolerant of long periods under water; indeed, some trees grow quite large despite staying underwater year round. Fires are not uncommon in riparian areas, and one would expect that as fire frequency increases, the proportion of rainforest species declines. If one compares the paperbark basal area ratio (the size of paperbarks to the total size of trees in a forest) with fire frequency, this does seem to be the case; the contribution of paperbarks to total basal area increases when fire frequency is greater than about 30% (6 out of 20 years – Figure 2).

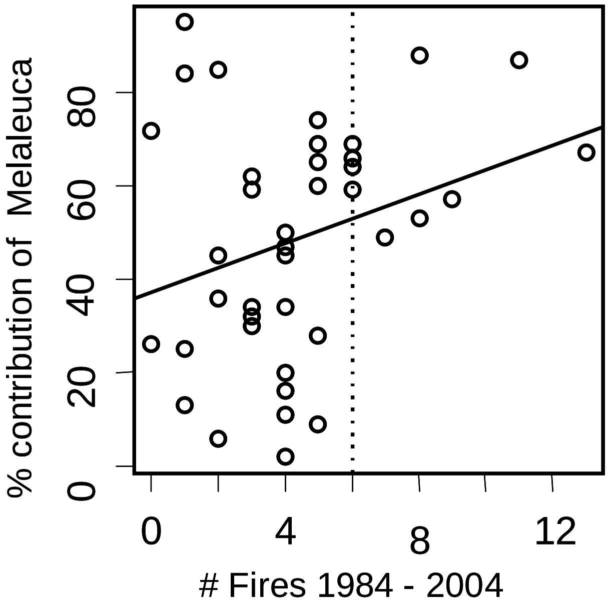

Figure 2 Fire frequency and composition of paperbarks in riparian forests. The y-axis shows the percent contribution of Melaleuca spp to total basal area. The remaining contribution to basal areas comes predominantly from rainforest species. The x-axis shows the number of fires that burned at a site from 1984 to 2004. The solid line is the trend line, which is signficant (p=.07). The dotted line illustrates cutoff point above which stands tend to have a higher basal area contribution from paperbarks. Fire data are from Landsat-derived fire scars provided by the NT Bushfires Council. Basal area data are from A Petty (unpublished).

An aerial photographic study of six riparian forests located in Mary River district shows that they are subject to fairly significant changes from decade to decade, but overall seem to be surprisingly stable with no noticeable change over 50 years (A Petty, unpublished data). Riparian forest appears to be constrained within the stream banks, either because of improved access to the water table, or due to a decreased likelihood of fire within the banks because of topography and higher ground moisture. Ongoing research into riparian communities located across the Park will give a more complete picture of the dynamics of riparian forests.

6.2.3 Agents of change

6.1.3.1 Fire

Although riparian areas are still important to bininj, they aren't visited as much as they were before the 1900s. The effect of this on riparian areas remains unknown, but the largest impact of depopulation is probably its effect on fire management. Today, the seasonally inundated savannas and upland savanna adjacent to streams are burnt frequently by the Park in the early dry season as they provide an important fire break.

Late season fires can have a profound effect on small seasonal streams. These streams have a very small or non-existent riparian forest component, and seasonally inundated savanna commonly directly abuts the stream. In a two year replicated experiment at Kapalga, Douglas (2001) found that stream vegetation by any measure declined significantly with late season fires (Table 1). Conversely, aquatic plants and in-stream macro-invertebrates increased, probably because of increased light. Equally important, early season fires (before Aug 1) were nearly indistinguishable from unburnt sites. Although larger riparian forests are probably more resistant to fire, this finding has relevance for the seasonally inundated savanna regions adjacent to larger perennial streams as they are comprised of comparable vegetation.

Bamboo patches will die off all at once after setting seed. This leaves behind a large amount of flammable fuel. Although bamboo is disadvantaged by too frequent fires it does seem moderately fire tolerant (Franklin & Bowman 2004) and fires do not seem to disadvantage seedling establishment (Franklin & Bowman 2003). When mature, bamboo is highly competitive, and that makes it difficult for the rainforest species that are often associated with bamboo to establish themselves. When bamboo dies off, a gap is created that other species can potentially exploit. Because bamboo seedlings are fire tolerant, fire will advantage them over other rainforest species (D Franklin, pers comm).

Table 1 Effect of fire regime on small streams (from Douglas 2001)

	Fire Regime		
Vegetation feature	**Unburnt**	**Early**	**Late**
Riparian richness	High	Med	Low
Riparian density	High	High	Low
Riparian canopy cover	High	Med	Low
Aquatic plant richness	Low	Low	High
Aquatic plant biomass	Low	Med	High

6.1.3.2 Feral animals

Pigs

Pig damage in riparian areas may not be as widespread as some fear. In a survey of 28 riparian sites located across Kakadu, Petty (unpub. data) found that almost one-third showed no evidence of pig damage (Figure 3a). However, pigs are a matter of great concern because they have a clear impact on plant recruitment (Figure 3b).

Buffalo

Most buffalo were removed from Kakadu as a result of the Brucellosis and Tuberculosis Eradication Campaign (BTEC) and today's population is much smaller than during their historical peak in the 1960s and 1970s, although locally high populations persist on the Arnhem Plateau (Petty et al in press). At their peak, they had a profound impact on riparian vegetation, particularly rainforest plants which declined due to trampling and soil compaction (Russell-Smith 1984, Skeat, East & Corbett 1996). The relation between paperbark forests and buffalo is more complex. In an aerial photographic analysis, DeLittle and L. Prior (pers. comm.) found that buffalo presence increased the local cover of paperbark trees. This may be due to buffalo's negative impact on fuel loads, which decreased fire frequency favouring paperbark recruitment. However, buffalo indirectly caused the destruction of localized stands of paperbarks from saltwater intrusion (Finlayson, Storrs & Lindner 1997).

6.1.3.3 Weeds

The weed of greatest concern for paperbark stands and riparian areas is para grass (*Urochloa mutica*). Para grass is an aggressive species that quickly dominates native vegetation and has a profound effect on food webs and animal habitats (Bunn, Davies & Kellaway 1997, Ferdinands, Beggs & Whitehead 2005). Moreover, para grass substantially increases grass fuel loads and hence fire intensity (Douglas & O'Connor 2004), posing a risk to fire sensitive rainforest species, seasonally inundated savanna, and potentially recruitment of paperbarks as intense fires kill seedlings.

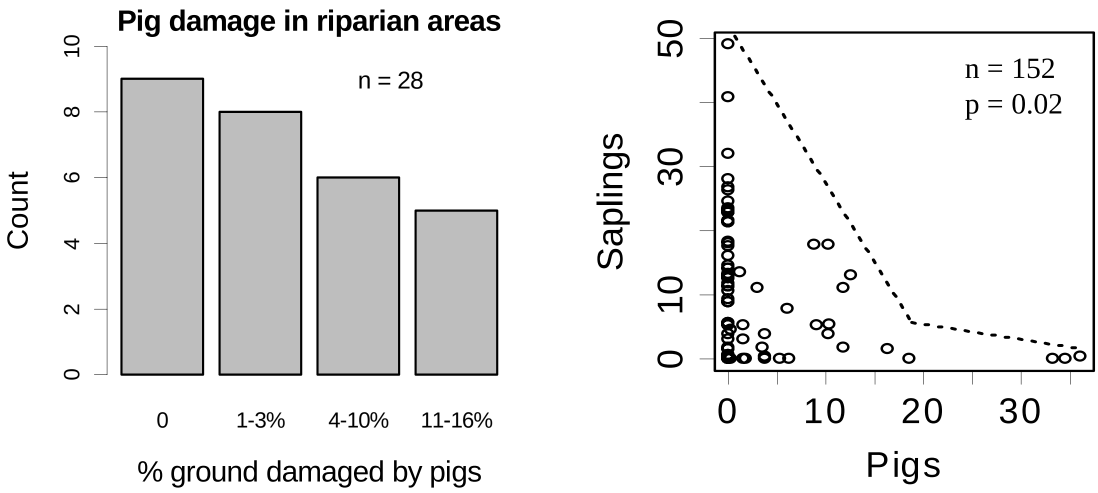

Figure 3 Left: Percentage of ground cover damaged by pigs in 28 riparian sites. Right: Percentage cover of saplings along 200m transects by percentage of ground cover damaged by pigs. Unpublished data from Petty.

Para grass prefers to grow in areas of long, sustained inundation (about 3–6 months) but is killed if water levels rise above the height of the grass. This might make para grass ideal for habitats occupied by the more water tolerant paperbark species. However, para grass is very intolerant of shading, and doesn't seem to occupy paperbark stands readily. This might change if para-grass changes the fire regime sufficiently to open up the paperbark canopy and permit colonisation. Riparian areas seem fairly resistant to para grass invasion because flooding is either too deep in the stream channel itself, or too episodic in the seasonally inundated savanna, but this aspect warrants further examination.

6.2.4 Knowledge Gaps

Despite their significance to Kakadu, riparian areas remain a very poorly studied ecosystem. We list below some of the most glaring knowledge gaps:

- The level of threat from weeds, particularly Para Grass, on paperbark forests and riparian areas is virtually unknown.
- Recruitment patterns are very poorly understood for riparian areas. Riparian areas suffer frequent disturbance from floods and fire, and seedling recruitment is particularly challenging for riparian species. In particular the role of fire and flooding in shaping riparian communities, and the impact of feral animals on recruitment warrant further study.
- Trends of change in riparian vegetation are presently unknown.
- The impact of bamboo die-offs on vegetation change is unstudied for Kakadu.

6.2.5 Management recommendations

- Feral animals, particularly pigs, are probably the greatest threat to riparian health, and a control program should be implemented.
- Fires in general are damaging to most riparian vegetation, particularly along small streams. However, early season fires are much less damaging to small streams than late season fires. In general, fires probably don't reach larger creeks and rivers until later in the dry season. The current practice of breaking up country with early season fires is likely optimal for riparian vegetation.

Continue to monitor the distribution of para grass and prevent its spread into major riparian systems and paperbark stands.

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7 Escarpment – fire effects on sandstone country

A Edwards[1], J Russell-Smith[1] & F Watt[2]

7.1 Focus summary

7.1.1 Analysis of fire history information with respect to sandstone habitats

Each of the three sandstone habitats was assessed to determine the fire regime. The fire parameters were: 1) the number of early dry season fires; 2) the number of late dry season fires and; 3) the shortest number of years between any two fires. The high resolution fire history dates back to 1996, the assessment was from 1996 to 2006, 11 years.

The number of times burnt by early dry season fires is an indication of the level of management. The average number of times an area burnt in the mixed woodland was about twice in nine years, in the heath communities this was once in nine years, and in the closed forests its about one fire in 20 years. This suggests that prescribed burning occurs more in the mixed woodlands surrounding the heaths and rainforests than in the heaths and rainforests themselves.

The number of times burnt by late dry season fires is an indication of the impact of hot wildfires on the habitats. Many species, particularly in heath communities, only come back from seed, so frequent hot fires in an area probably means extinction of that species in that area. Our analysis shows there is not much difference in the average number of times all three habitats have been affected by hot late dry season fires, it suggests that, on average, there is a hot fire through the heath and the mixed woodland habitats approximately once every six years and once every eight and a half years in the rainforests.

The shortest number of years between fires indicates how the fire regime is affecting those plants that only come back from seed. If a plant such as the Rock Myrtle (*Petraeomyrtus punicea*) takes six years to grow old enough to start producing seed itself, then we need at least a six year gap between fires in those heath communities where we want Rock Myrtle to grow. Nearly three quarters of the heath habitat has had fires with intervals of 6 years or less. Cypress pine (*Callitris intratropica*) seedlings take nearly ten years to mature to produce seed, but only 10% of the whole sandstone plateau received intervals more than 9 years. This would suggest that Cypress pine are not likely to be as widely spread across the plateau as we know they used to be.

7.1.2 Main threats

To respond to the question as to whether the current regime is good for the plant communities? We would have to say that as far as the indicator species are concerned they are not doing so well. As for species who don’t require as many years to mature, over half of the

[1] Bushfires Council of the Northern Territory & Tropical Savannas Cooperative Research Centre
[2] Bushfires Council of the Northern Territory

heath habitat has had no more than two years between fires at least once in the nine year assessment so most of them might not be doing so well.

It would seem some effort is going into protecting the heaths and the rainforest patches by the amount of burning that is occurring in the early dry season in the surrounding woodlands, however, big hot fires are still affecting large areas of heaths and impacting on many rainforest patches.

7.1.3 Proposed management

As a general guideline to fire management on the sandstone the following need to be undertaken:

- much more patchy, early burning across the heaths, so as to lower the intensity and thoroughness with which these communities are burnt by late dry season wildfires;
- early dry season fire breaks around rainforest patches reducing the grassy fuel component that can carry hot fires into the rainforest;
- throughout the woodlands on the sandstone plateau, continued effort in burning a patchy mosaic of early dry season fires;
- along the creek lines, reducing fuel and to improve the creek lines as fire breaks.

In each instance there needs be a level of planning for fuel reduction, fire breaks and ecological impacts. Fire mapping information, derived from high resolution satellite imagery available at the end of each year, needs to be considered with respect to habitat and the historical fire regime. Frequency of hot fires needs to be low, one rather than two fires in 10 years across the heaths and in the rainforest patches. The number of years between successive hot fires in any patch needs to be lowered to assist obligate seeder species with longer times to maturation and as a guide should never be less than five years but preferably longer.

7.1.4 Knowledge gaps

Currently, fire history information is used sparingly in fire planning operations. These data are the best picture for understanding the historical placement and movement of fire.

A useful management process is to undertake visual assessment of areas that the fire mapping indicates are under threat, in conjunction with ecological thresholds. Ecological thresholds need to be determined from the general guidelines mentioned earlier, from the knowledge of land managers in the park/s, from the advice of traditional owners and from the knowledge of scientists who have studied the effects of fire on the vegetation and the fauna. This knowledge could be general as I have provided above, or for specific areas such as for the management of Acacia ‘Graveside Gorge’.

The three main requirements to assist fire management on the sandstone in Kakadu National Park are:

1 Improved use of the available historical fire mapping as part of a consultative planning process;

2 Improved habitat mapping of various and appropriate scales, including known locations of rare and threatened species/habitats;

3 A consolidated approach to the undertaking of on-ground fire management.

7.2 Paper

7.2.1 The Arnhem Plateau

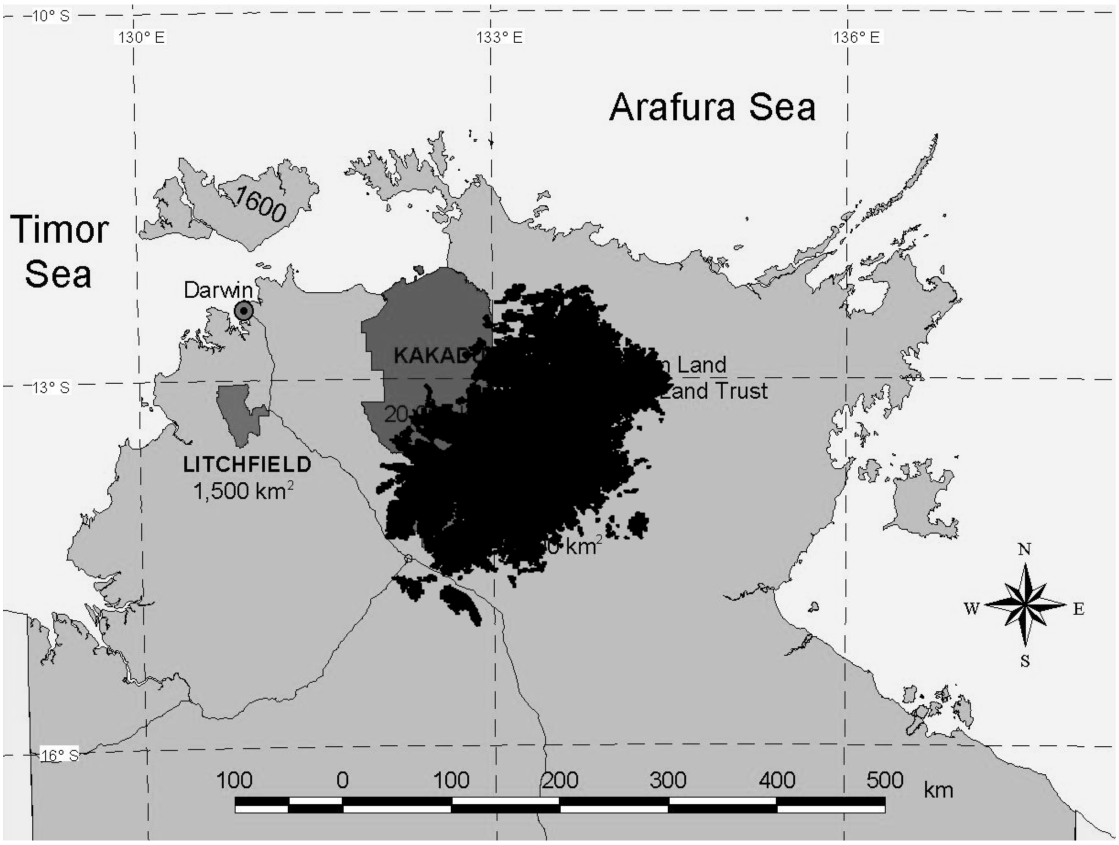

Figure 1 The location of the Arnhem Land plateau in the 'Top End' of the Northern Territory

The Arnhem Plateau's western edge rises some 200–300m above the surrounding lowland area creating spectacular escarpment cliffs pocketed with monsoon jungle patches. The plateau itself is comprised of resistant, flat sandstones criss-crossed by deeply weathered and eroded joints to form a maze of narrow valleys and gorges. There is very little soil but where it occurs it is mostly infertile sand, in the east and south-east of the plateau there are extensive deep sand plains.

The vegetation is characterised by low open woodland with scattered trees, such as *Eucalyptus, Gardenia* and *Terminalia.* The area also contains a complex mix of shrubby communities referred to as 'Sandstone Heath' communities, examples of dominant species are *Acacia, Asteromyrtus, Calytrix, Hibbertia, Hibiscus, Pityrodia* and *Tephrosia*, where the understorey is often interspersed with a substantial cover of highly flammable hummock Spinifex grasses (*Triodia*). On the deep sand plains the trees generally grow much taller taking on an open forest structure, dominated by Darwin Stringy Bark *Eucalyptus tetrodonta* and Darwin Woolly Butt *Eucalyptus miniata* over an understorey of shrubs and slender perennial and annual grasses, such as *Aristida*, *Eriachne*, *Schizachyrium* and *Sarga*. There are closed forest patches with an average area of approximately 5 hectares occurring in a variety of suites and situations: rainforest patches dominated by the myrtaceous sclerophyll *Allosyncarpia ternata* typically found in rugged terrain but also found in patches around springs and ; riparian strips dominated by paper barks (*Melaleuca*) in dense majestic corridors lining perennial rivers and creeks; (Russell-Smith et al 1993, 1998).

7.2.2 Habitat mapping and a fire history

A preliminary habitat map of the sandstone country within Kakadu National Park was compiled for analysis. The two communities, closed forest and sandstone heath communities were found to be most at risk, the most sensitive to fire and therefore the best possible indicators of the effects of fire. The spatial data compiled to describe the three main communities were:

- Heath communities – derived by G Blake in the honours thesis at Charles Darwin University: 'Object Oriented Mapping of Sandstone Heath'; (758 km^2)
- Closed Forest communities – Jeremy Russell-Smith and Diane Lucas, unpublished data for NT Parks & Wildlife; (142 km^2)
- Mixed woodland – the areas being neither heath nor closed forest, (3525km^2).

Since 1995 the fire history for Kakadu National Park has been under the custodianship of Bushfires NT and has been derived from high resolution LANDSAT satellite imagery with 30m x 30m pixels. The Kakadu National Park fire history now covers 27 years (1980–2006).

Spatial analyses were undertaken for the three main sandstone communities based on characteristics of indicator species within that habitat type. In the heath community there are many species often that do not re-sprout after fire and can take a great number of years to grow to maturity to produce seeds. The most notable is the Rock Myrtle (*Petraeomyrtus punicea*) formerly known as Regelia. The information available to us suggests that most fires will kill the adult plant and it takes a minimum of six years for seedlings to mature to produce seed (Russell-Smith 2006) (see Figure 2).

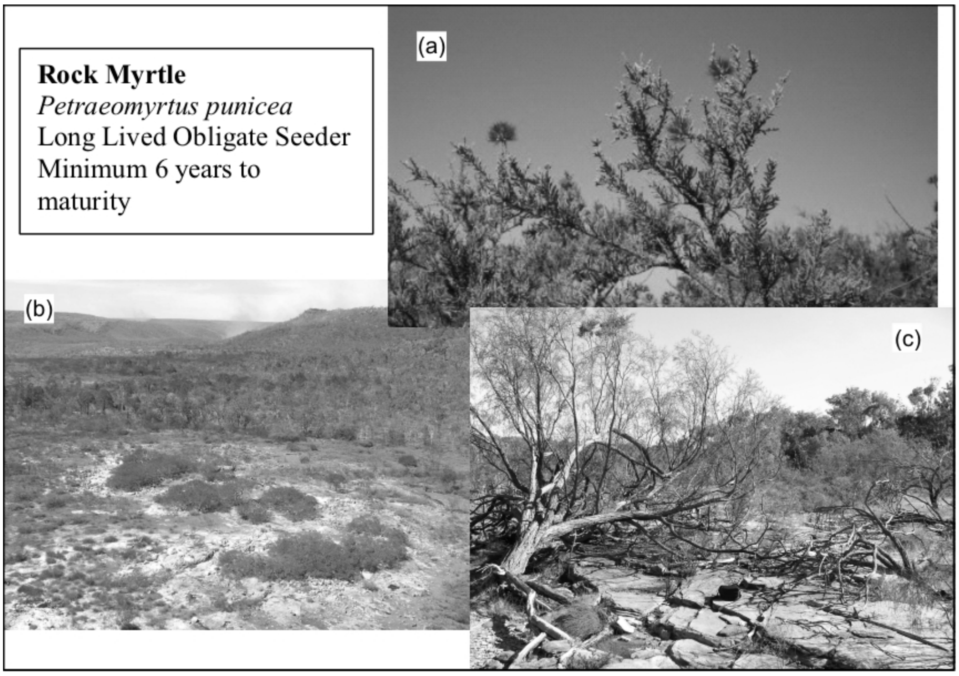

Figure 2 Rock Myrtle: A long-lived obligate seeder found in sandstone heath communities: (a) a close up of the plant showing flowers; (b) a typical location on a rock sheet away from any fire; (c) a dead adult, not burnt just killed by the heat.

Another notable species is the Cypress Pine (*Callitris intratropica*). This tree is very obvious in the landscape and, as it is termite resistant, its dead stems remain standing for, sometimes, many years after the tree is killed. It is able to grow in most soil types in the region and is relatively fire tolerant (Bowman et al 2001). Measurements from studies undertaken in

Kakadu National Park suggest it can take up to 10 years or more to mature and produce seed (Russell-Smith 2006).

The question then is: are the current burning practices in Kakadu National Park helping or hurting these communities of plants?

7.2.3 Analysis of fire history information with respect to habitats

Each of the three sandstone habitats was assessed to determine the fire regime. The fire parameters were: 1) the number of early dry season fires; 2) the number of late dry season fires and; 3) the shortest number of years between any two fires. The high resolution fire history dates back to 1996, the assessment was from 1996 to 2006, 11 years.

The number of times burnt by early dry season fires is an indication of the level of management. The average number of times an area burnt in the mixed woodland was about twice in nine years, in the heath communities this was once in nine years, and in the closed forests it's about one fire in 20 years (see Figure 3). This suggests that prescribed burning occurs more in the mixed woodlands surrounding the heaths and rainforests than in the heaths and rainforests themselves.

The number of times burnt by late dry season fires is an indication of the impact of hot wildfires on the habitats. As has already been stated, many species, particularly in heath communities, only come back from seed, so frequent hot fires in an area probably means extinction of that species in that area. Our analysis shows there is not much difference in the average number of times all three habitats have been affected by hot late dry season fires, it suggests that, on average, there is a hot fire through the heath and the mixed woodland habitats approximately once every six years and once ever 8 and a half years in the rainforests.

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To respond to the question as to whether the current regime is good for the plant communities? We would have to say that as far as the indicator species are concerned they are not doing so well. As for species who don't require as many years to mature, over half of the heath habitat has had no more than two years between fires at least once in the 9 year assessment so most of them might not be doing so well.

It would seem some effort is going into protecting the heaths and the rainforest patches by the amount of burning that is occurring in the early dry season in the surrounding woodlands, however, big hot fires are still affecting large areas of heaths and impacting on many rainforest patches. The solution might be to undertake much more patchy, early burning across the heaths, around rainforests and throughout the woodlands on the sandstone plateau.

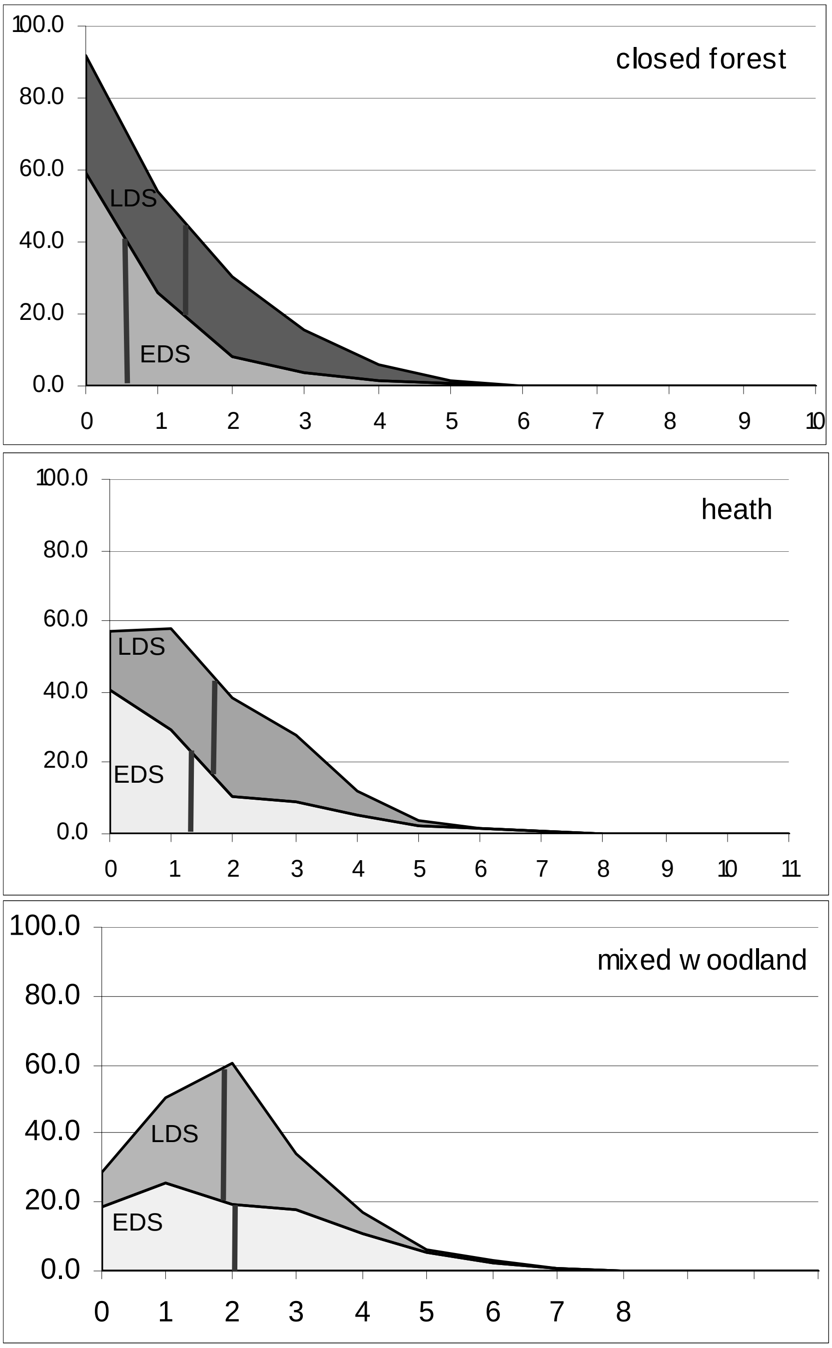

Figure 3 Proportion of the number of times burnt of each habitat 1996-2006. The solid vertical line is the average.

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8 Rainforests

D Bowman[1] & L Prior[2]

8.1 Focus summary

8.1.2 Lowland rainforests in KNP

A recent PhD study by Daniel Banfai investigated what has been happening to rainforests in KNP, using 29 dry 21 wet rainforest patches in lowland areas of KNP. Aerial photographs showed a steady increase in average size of these rainforest patches over the last 40 years (Figure 2). On average, the increase was 29%, but it was higher for dry rainforests (42%) than for wet rainforests (13%).

Rainforests were more likely to expand where there was little impact of buffalo and more likely to contract when buffalo impact was obviously high. Surprisingly, this study found only weak evidence that fire affected rainforest expansion or contraction, but this was probably because of the poor spatial resolution of the fire scar mapping, and also because the impact of fire on the rainforest boundaries depends on the fuel type present in the surrounding savanna. Studies of individual patches showed that there was an effect of topographic fire protection and flammable weeds. However, while buffalo and fire affected the boundary dynamics of these patches, they cannot account for the overall expansion that has occurred. This expansion appears to have been driven by factors that have varied on a regional scale, such as increasing rainfall and atmospheric CO_2.

8.1.3 Allosyncarpia rainforest

As with lowland rainforests, there has been concern that changed fire regimes may have caused *Allosyncarpia* forests to contract over the last half-century. Aerial photographs were obtained for 4 times between 1964 and 1984, and used to estimate the area of *Allosyncarpia* at 12 sites. Area of *Allosyncarpia* increased at 11 of the 12 sites over the 40 year period, with an overall increase of 21% (Figure 3). *Allosyncarpia* forests were more likely to expand in areas that had experienced few fires than in frequently burnt areas.

8.1.4 Management implications

There are several management implications of these studies:

- rainforest boundaries are dynamic, but continuation of the current fire regime is likely to allow rainforest patches to continue to expand, whereas
- a shift to frequent late dry season fires would probably cause rainforests to contract where there is a high fuel load on the boundary;
- management of flammable weeds on rainforest boundaries should therefore be a priority in maintaining rainforest patches;

[1] University of Tasmania, TAS
[2] School for Environmental Research, Charles Darwin University, Darwin NT 0909

- keeping buffalo numbers low is also important in maintaining lowland rainforests.

Continued monitoring of rainforest patches by aerial photography and ground surveys is important for park staff to assess the effects of their fire and feral animal management programs. This should include keeping field records of fire and buffalo impacts to help future understanding of the impacts of these disturbances on rainforests in KNP.

8.2 Paper

8.2.1 Characteristics of rainforests

Monsoon rainforests form an archipelago of small patches (typically <5 ha) embedded in a matrix of fire-prone vegetation across the Top End. They occur on a variety of soils and landforms, but can be grouped into two main categories: (i) wet rainforest springs and other perennially wet areas and (ii) dry rainforest on seasonally dry areas that are to some extent protected from fire, such as rock outcrops, beach ridges, floodplain margins, cliffs, talus slopes and sandplains (Russell-Smith et al 1997).

Compared with savanna trees, rainforest trees are generally more fire-sensitive, mainly because they do not resprout as vigorously after fire and many species are also less likely to reproduce clonally (Russell-Smith & Setterfield 2006). Under a regime of recurrent fires rainforest boundaries vulnerable to contraction following fire, especially when flammable weeds are present.

Given all the changes in fire regimes that have occurred in the Kakadu region during the last century, what has been happening to rainforest patches here, and why? A recent PhD study by Daniel Banfai (Banfai 2007) has helped answer these questions.

8.2.1.1 Lowland rainforests in Kakadu National Park

Twenty-nine dry and 21 wet rainforest patches in lowland areas of Kakadu National Park (KNP) were chosen for this study (Figure 1). Aerial photographs showed a steady increase in average size of these rainforest patches over the last 40 years (Figure 2). On average, the increase was 29%, but it was higher for dry rainforests (42%) than for wet rainforests (13%) (Banfai & Bowman 2006). While the average value for the dry rainforests was skewed by a few that expanded dramatically, about 30% of the rainforest patches expanded over the 40 years, compared with 20% that contracted. A reassessment of the overall rate of change based on statistical analysis of the rates of change for all possible combinations of aerial photographic intervals (so called ‘bootstrapping’) supported the occurrence of an overall expansion of rainforest in Kakadu National Park, however it also suggested that the rate of change had been overestimated for dry rainforest (Banfai & Bowman 2006). The fact that rainforests have increased in average size may be surprising, but similar trends have been observed in rainforests in Litchfield National Park (Banfai & Bowman 2005) and the Gulf Country (Brook & Bowman 2005).

Rainforests were more likely to expand where there was little impact of buffalo (as indicated by density of tracks apparent in aerial photographs), and more likely to contract when buffalo impact was obviously high (Banfai 2007). Surprisingly, this study found only weak evidence that fire affected rainforest expansion or contraction, but this was probably because of the poor spatial resolution of the fire scar mapping, and also because the impact of fire on the rainforest boundaries depends on the fuel type present in the surrounding savanna. Studies of individual patches showed that there was an effect of topographic fire protection and flammable weeds. However, while buffalo and fire affected the boundary dynamics of these patches, they cannot account for the overall expansion that has occurred. This expansion appears to have been driven by factors that have varied on a regional scale, such as increasing rainfall and atmospheric CO_2 (Banfai 2007).

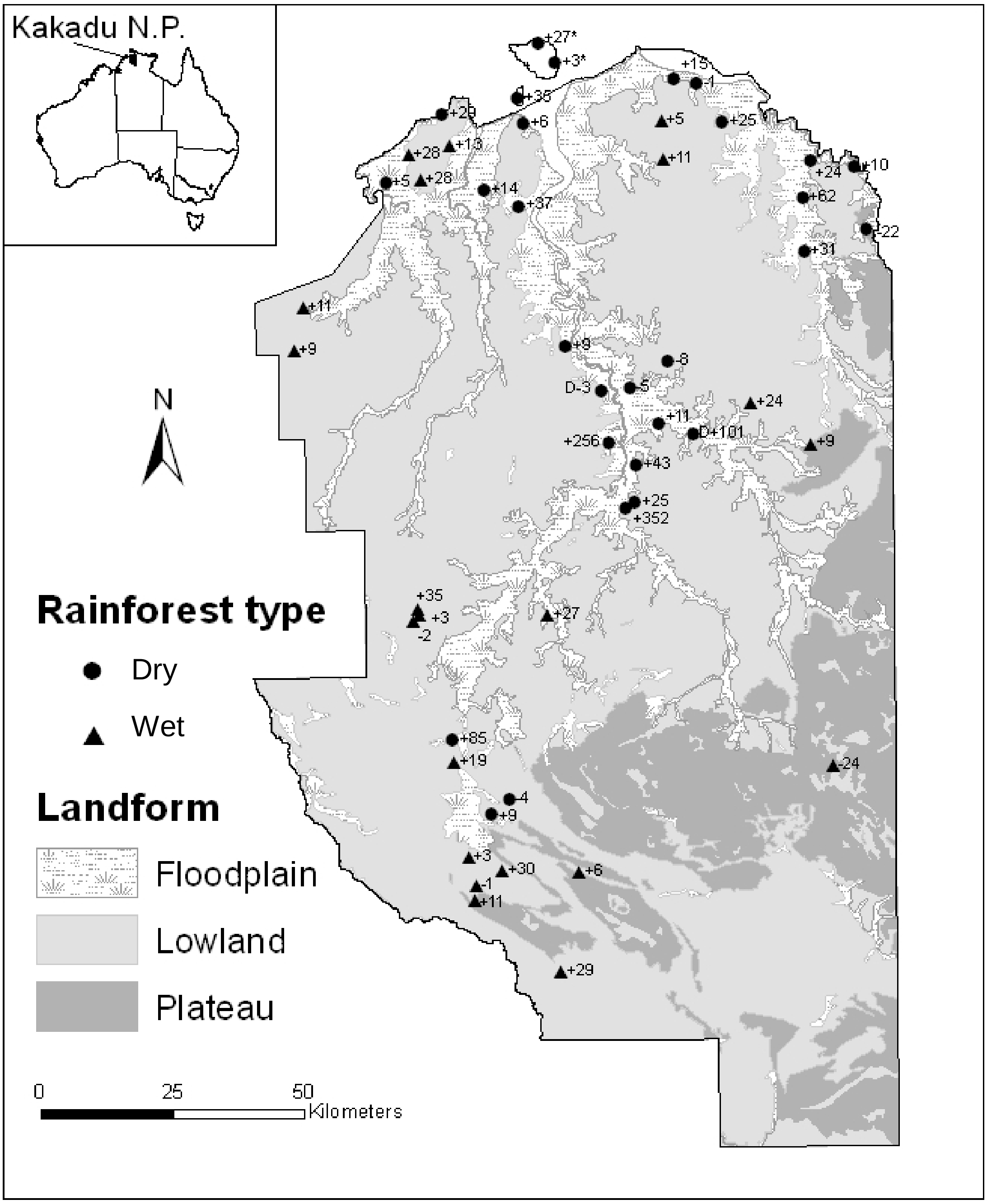

Figure 1 Location of rainforest study patches, and percentage change in area over the period 1964-2004. Circles indicate dry rainforest, and triangles wet rainforest. From Banfai & Bowman (2006).

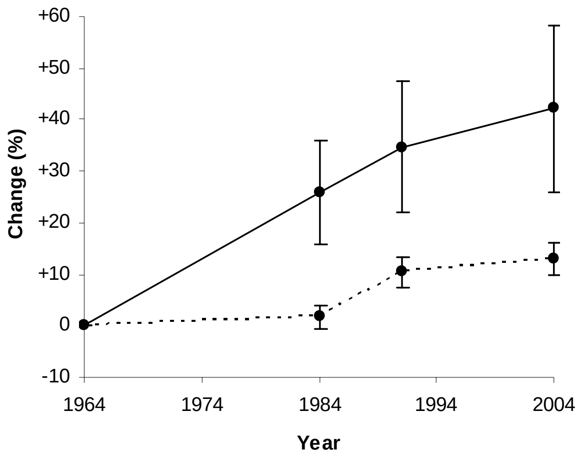

Figure 2 Average percentage change in area of rainforest patches in KNP relative to 1964. The solid line indicates dry rainforest patches, the dotted line wet rainforest patches.
From Banfai & Bowman (2006).

8.2.1.2 Allosyncarpia rainforest

Allosyncarpia ternata forests occur only on the western edge of the Arnhem Land plateau. About 42% of these forests are reserved in KNP. *Allosyncarpia* forests are fragemented, and are found on both perennially moist and seasonally droughted sites, and on either rocky or deep, sandy soils.

As with lowland rainforests, there has been concern that changed fire regimes may have caused *Allosyncarpia* forests to contract over the last half-century. In order to investigate this possibility, 12 study sites containing *Allosyncarpia* forest (representing 13% of the total area of this forest in KNP) were selected for study (Bowman & Dingle 2006). Aerial photographs were obtained for 4 times between 1964 and 1984, and used to estimate the area of *Allosyncarpia* at the 12 sites. The initial area of *Allosyncarpia* at each of the 12 sites ranged from 27 to 651 ha. Area of *Allosyncarpia* increased at 11 of the 12 sites over the 40 year period, with an overall increase of 21% (Figure 3). *Allosyncarpia* forests were more likely to expand in areas that had experienced few fires than in frequently burnt areas.

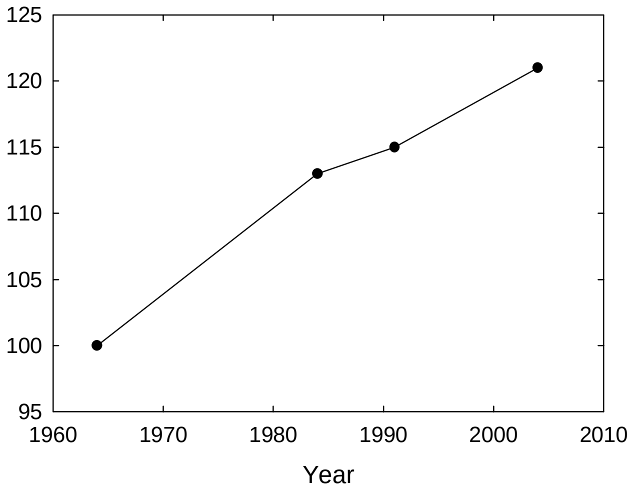

Figure 3 Total area of *Allosyncarpia* at the 12 study sites has increased steadily over the last 40 years.
Based on Bowman & Dingle (2006).

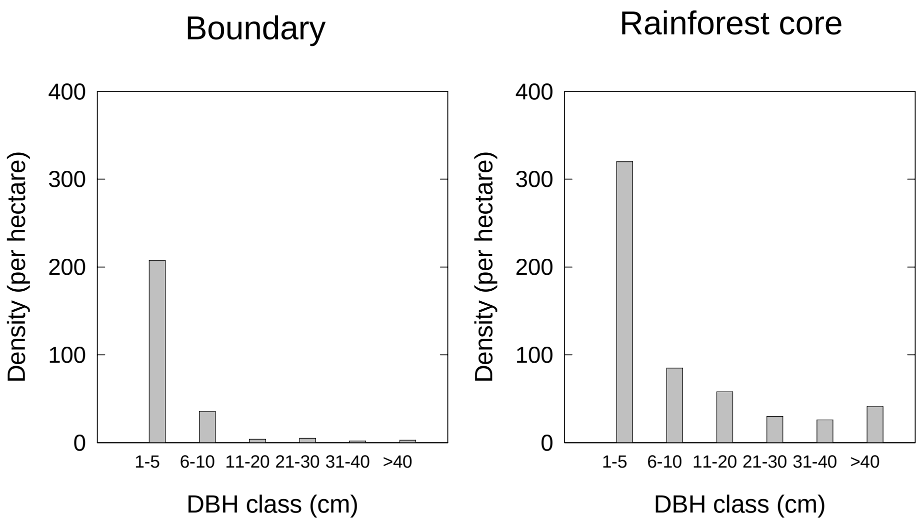

Figure 4 Density of *Allosyncarpia* stems at the boundary and in the core of rainforest at Round Jungle, KNP in 2005. Note that there were relatively few large stems (> 30 cm DBH) on the boundary compared with the rainforest core, probably because they are killed by fires burning in from surrounding savanna.

A field study at Round Jungle found that although the numbers of large *Allosyncarpia* trees (> 20 cm diameter at breast height, DBH) on the rainforest boundary had declined over 16 years, populations were sustained by vigorous re-sprouting of fire-killed or damaged trees (Prior et al 2006), so that patch size was maintained or even increased. There is, however, likely to be a long-term change in the stand structure on the boundaries of these forests, with more small trees and fewer large trees making up the population.

8.2.2 Management implications

There are several management implications of these studies:

- rainforest boundaries are dynamic, but continuation of the current fire regime is likely to allow rainforest patches to continue to expand, whereas
- a shift to frequent late dry season fires would probably cause rainforests to contract where there is a high fuel load on the boundary;
- management of flammable weeds on rainforest boundaries should therefore be a priority in maintaining rainforest patches;
- keeping buffalo numbers low is also important in maintaining lowland rainforests.

Continued monitoring of rainforest patches by aerial photography and ground surveys is important for park staff to assess the effects of their fire and feral animal management programs. This should include keeping field records of fire and buffalo impacts to help future understanding of the impacts of these disturbances on rainforests in KNP.

Under the current upward trend of atmospheric CO_2 and increasing wet season rainfall expansion of rainforest will probably continue. How this influences the regional carbon budget remains uncertain. The expansion of rainforests may be one of the few positive aspects of global climate change.

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9 Invasive species. Feral animal species in northern Australia: savvy surveillance and evidence-based control

CJA Bradshaw[1]

9.1 Focus summary

9.1.1 Introduction

Non-indigenous animal species threaten biodiversity and ecosystem stability by damaging or transforming habitats, killing or out-competing native species and spreading disease. Available evidence suggests that large feral herbivores such as Asian swamp buffalo, pigs and horses are the most ecologically threatening species in Kakadu National Park. A comprehensive overview of current and future threats posed by non-indigenous animal species in northern Australia is sorely needed to contextualise their impact relative to other factors menacing biodiversity in this region of high endemicity and comparatively low post-settlement extinctions. Here I consider the main non-indigenous animal threats to native north Australian biota in World Heritage Area Kakadu National Park. To do this, I (1) assess the current and potential range, diversity and intensity of risks posed by non-indigenous animal species to KNP's ecological integrity, (2) evaluate the costs and benefits of past, current and proposed management and restoration options in KNP, (3) Identify some of the most likely non-indigenous candidates that may invade KNP in the future.

9.1.2 Current threats and challenges

- Many species damage the landscape (pigs, buffalo, horses), spread weeds (horses, pigs).
- Feral cats and dogs may outcompete native species
- There is postulated hybridisation between feral dogs and native dingoes.
- Black rats exhibit destructive behaviour that may have ecosystem-wide consequences
- There is little information on the impacts of house mice
- Cane toads are regarded as one of the greatest problem species in KNP (predation and poisoning native species)
- The African big-headed ant eliminates native ants and many other invertebrates from rainforest sites
- European bees are inefficient pollinators and may outcompete native bees
- Feral pigs, buffalo and horses are prominent reservoirs for exotic and endemic disease and parasites
- Control options for large herbivores are generally restricted to broad-scale helicopter shooting campaigns

[1] School for Environmental Research, Charles Darwin University, Darwin, Northern Territory 0909

- Animal control may be compromised by entry of animals from neighbouring regions
- Feral horse management elicits particular controversy in KNP
- It is difficult or impossible to defend control programs when there has been no clear demonstration of detriment

9.1.3 Future threats

A number of non-indigenous species that have established populations in the regions surrounding KNP, but many have yet to establish in the Park. Those that pose the greatest risk to KNP include yellow crazy ants, mosquito fish and rock pigeons. Although it is unlikely that KNP will be able to have much influence on the introduction and spread of non-indigenous species outside of its boundaries, it is in their interest to make some investment into reducing their potential spread across northern Australia. Failure to take interest in such issues may ultimately expose the Park to costly and intrusive management responses.

9.2 Paper

9.2.1 Introduction

Non-indigenous animal species threaten biodiversity and ecosystem stability by damaging or transforming habitats, killing or out-competing native species and spreading disease. Available evidence suggests that large feral herbivores such as Asian swamp buffalo, pigs and horses are the most ecologically threatening species in Kakadu National Park. A comprehensive overview of current and future threats posed by non-indigenous animal species in northern Australia is sorely needed to contextualise their impact relative to other factors menacing biodiversity in this region of high endemicity and comparatively low post-settlement extinctions (Woinarski et al 2006). Here I consider the main non-indigenous animal threats to native north Australian biota in World Heritage Area Kakadu National Park. To do this, I (1) assess the current and potential range, diversity and intensity of risks posed by non-indigenous animal species to KNP's ecological integrity, (2) evaluate the costs and benefits of past, current and proposed management and restoration options in KNP, (3) Identify some of the most likely non-indigenous candidates that may invade KNP in the future.

9.2.2 Current threats and challenges

Many non-indigenous animal species are known to have established wild populations in KNP. The principal non-indigenous species currently occupying KNP include pigs, buffalo, cattle, horses, donkeys, cats, dogs, black rats, mice, cane toads, ants and honeybees. Two non-indigenous reptiles also occur in KNP – the flower-pot snake and the house gecko – but their distributions and impacts are considered to be minimal (Cogger 2000). Current control programmes (and those planned in for the foreseeable future) are likely to be set using control targets, funding availability, and the maintenance of public safety. The management challenges raised by these major non-indigenous animal populations in KNP are particularly problematic given the potential severity of their impacts and the diversity of interests and expectations from the broad range of interested groups.

9.2.3 Physical impacts

Damage arising from pigs mainly occurs as a result of digging for food in soft soils (Tisdell 1982), although other damage includes population-level effects on the wide range of plant, invertebrate and vertebrate prey pigs consume. Pig predation was a cause of a substantial increase in snake-necked turtle mortality in northern Australia (Fordham et al, 2006). Another example of the potential magnitude of pig impacts in KNP is that the costs associated with feral pig damage and control in the USA alone exceeded AU$1 billion per year (Pimentel et al 2001). In the Northern Territory, pigs have a limited effect on ground vegetation cover in monsoon forest remnants (eg Bowman & McDonough 1991, Bowman & Robinson 2002), although their impact is far greater in some isolated wetlands (Bowman & Panton 1991). This type of damage is particularly acute in KNP's extensive wetland networks.

After the collapse of the buffalo-hide industry in the 1950s, an unrestricted population explosion of feral buffalo caused severe damage to the lowland environment (Mulrennan & Woodroffe 1998, Skeat et al 1996) which has only partially recovered in recent years. Adult buffalo are large animals (500 to 1200 kg) that consume up to 30 kg of food per day within relatively restricted home ranges (Tulloch & Cellier 1986). It is through these habitual behaviours and high densities (up to 34 individuals/km^2) make buffalo particularly efficient at damaging their environment. The types of damage inflicted have been studied extensively (Letts 1979, Petty et al 2007, Robinson & Whitehead 2003, Skeat et al, 1996, Taylor & Friend 1984). Damage caused by feral horses has never been studied directly in northern Australia; however, anecdotal and photographic evidence supports claims that they contribute to erosion, damage vegetation and disperse weeds (Letts 1979). Donkeys are likely to have similar impacts to the vegetation and land degradation as feral horses, although their distribution may be limited currently to drier (southern) regions within the Park.

Feral cats consume a wide range of native vertebrate fauna (Dickman 1996), and it has also been suggested that they are potential competitors with some native carnivorous predators for prey. Among native predators in KNP, the already *Endangered* northern quoll has the closest dietary overlap with feral cats and may coexist in forest and woodland habitats (Dickman 1996). Feral cats may also compete with some species of elapid snakes and goannas (King & Green 1993, Shine 1991). With no information on cat densities it has proven difficult to demonstrate their association with observed declines of native species in northern Australia, although they are suspected to play a role. This is most likely due to the difficulty of implementing effective control with which to test their capacity to reduce native species abundance and diversity.

The diet of feral dogs in KNP is likely to be similar to that of dingoes, and their foraging may impact on the native wildlife by increasing both competition for food with other native predators and by reducing the densities of prey species important for endangered or threatened native predators (Fleming et al 2001). Specifically within KNP, a greater problem may be the postulated hybridisation between feral dogs and native dingoes.

Black rats are pests that have a large economic impact on Australian agriculture industries (Department of Environment and Heritage 2005). In the eastern forests of Australia, black rats are omnivorous (Watts 2002) and it has been suggested that in undisturbed or largely unmodified areas, black rats can displace native species (Ramanamanjato & Ganzhorn 2001, Watts 2002). In unmodified habitats, black rats exhibit destructive behaviour that may have ecosystem-wide consequences, such as stripping bark from trees and the consumption of plant root systems. There is little information on the impacts of house mice, although this species is considered to be a greater threat to biodiversity than black rats given their relatively higher ecological flexibility (Caughley et al 1998).

Cane toads are regarded as one of the greatest problem species in KNP because of their predatory behaviour and, more particularly, their capacity to poison and kill their predators.

Although no native Australian species is known to have been pushed to extinction by the invasion, the arrival of cane toads appears to have substantially reduced the abundance of monitor species on some islands within the Great Barrier Reef (Burnett 1997, Lever 2001), and there is anecdotal evidence for a decline in goanna species in north Queensland (Burnett 1997). Recent radio-tracking work just east of Darwin has confirmed a strong effect of cane toad presence on reducing goanna survival. Further, a large decrease in goanna populations has been observed following the arrival of cane toads to the Northern Territory (Doody et al 2006). Cane toad tadpoles are also poisonous, with a 100 % mortality observed in a freshwater snail species (Crossland & Alford 1998). Species known to be preferred as prey by cane toads have also been shown to decline subsequent to invasion (Catling et al 1999, Lever 2001, Taylor & Edwards 2005), especially where these taxa were already restricted in occurrence.

The African big-headed ant eliminates native ants and many other invertebrates from rainforest sites (Hoffmann et al 1999) that probably has negative repercussions for other fauna and flora. For non-indigenous honeybees, the most important issues are their potential for competition with native birds and insects and hence, interference with pollination of plants dependent on native pollinators. European bees are thought to be inefficient pollinators of many plants (Westerkamp 1991), and high densities can cause lower pollination rates and compromised seed production in Australian native plants (Paton 1996, Vaughton 1996). Some Aboriginal people in northern Australia have expressed concern over the potential for feral honey bees to displace native social bees and so reduce the abundance of 'sugarbag', the so-called honey made by native bees (Sugden & Pyke 1991). If there are similar effects in northern Australia with the local bee species, then harvest of sugarbag may be compromised.

9.2.4 Disease

Feral pigs, buffalo and horses are prominent reservoirs for exotic and endemic disease and parasites that can affect native wildlife, stock, and humans. Perhaps the greatest disease concern is the Japanese encephalitis virus that has been tracked across Southeast Asia over the past 20 years and has been found recently in Torres Strait pig populations (Department of Health and Ageing 2004). Pigs are the important amplifier hosts that do not show signs of infection and allow transmission to humans through mosquitoes (Department of Health and Ageing 2004).

Bovine tuberculosis is currently re-emerging as one of the more difficult management problems for major biodiversity reserves such as Kruger National Park in South Africa (Cross & Getz 2006). The Brucellosis and Tuberculosis Eradication Campaign (BTEC) (Robinson et al 2003) saw the destruction of approximately 80,000 buffalo from KNP Between 1980 and 1989 and was considered largely successful in eradicating BTB from Australia. BTB is an airborne pathogen that causes chronic and progressive bacterial disease from which few animals recover (Bengis et al 1996). The disease's potential economic implications for Australia are massive – costs ranging from AU$8 – 13 billion for eradication and lost exports would be felt by the Australian livestock industry if a disease such as BTB or worse, foot-and-mouth disease, were to become established in wild or domesticated ungulates in Australia (www.daff.gov.au).

9.2.5 Management and control challenges

The threats and damage caused by many of the aforementioned species are overt and severe enough that most people desire some form of control. Control options for large herbivores are generally restricted to broad-scale helicopter shooting campaigns, although the technique is expensive and labour-intensive (Choquenot et al 1999, Hone 1986). Budget restrictions and opportunistic culls can often result in no more than a sustained off-take that does not reduce target species densities or landscape damage (Braysher 1993). Another problem that may arise when attempting to justify the high costs of maintaining effective control is the lack of quantitative studies examining the relationship between animal density reduction and the hypothesised decrease in environmental damage expected, even though the amount of damage and threat to native biodiversity may appear intuitive.

Furthermore, efforts to control damage are likely to be compromised by entry of animals from neighbouring regions whose human occupants either lack interest or funds to implement broad-scale control, have reservations given the lack of evidence for general density-damage relationships, or have fundamentally different management goals. For some species, there are competing cultural, ethical and political interests that render the decision to reduce non-indigenous animal densities controversial.

Feral horse management elicits particular controversy in KNP because whilst horses have the potential to cause large-scale environmental and economic damage, many Aboriginal people have accepted them as part of the landscape and their presence is not considered unusual (Australian National Parks and Wildlife Service 1991). As such, horses are now partially protected by Aboriginal people by exercising their rights to biological resources. Thus, widespread shooting is not seen as an acceptable management option in many parts of KNP, as is the case elsewhere in Australia where control programs for horses also tend to attract close attention from both rural and urban people, including animal welfare, Aboriginal and horse-protection groups (Caughley et al 1998, Rose 1995), and are often accompanied by intense scrutiny and political lobbying (English 2001).

As with many other feral species, it is difficult or impossible to defend control programs when there has been no clear demonstration of detriment from a non-indigenous species' presence (Symanski 1994), even though anecdotal and photographic evidence may be convincing. It is certainly difficult to justify costly large-scale density-reduction programmes for species such as cats, dogs, rats and mice when there is little information on population densities or evidence for a harmful threat to native wildlife.

9.2.6 Future threats

A number of non-indigenous species that have established populations in the regions surrounding KNP, but many have yet to establish in the Park. Those that pose the greatest risk to KNP include yellow crazy ants, mosquito fish and rock pigeons. Although it is unlikely that KNP will be able to have much influence on the introduction and spread of non-indigenous species outside of its boundaries, it is in their interest to make some investment into reducing their potential spread across northern Australia. Failure to take interest in such issues may ultimately expose the Park to costly and intrusive management responses.

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10 Invasive species. Weed management in Kakadu National Park

D Walden[1] & M Gardener[2]

10.1 Focus summary

10.1.1 Current knowledge

- Weed Management Strategy 1996–2001
- System of identification, mapping, planning and monitoring
- Informal assessment of priorities
- Knowledge on ecology and dispersal pathways
- Limited management tools
- KNP – 120+ species
- ERA leases – 71+ species
- Jabiru town – 55+ species
- KNP priority species – mimosa, water hyacinth*, olive hymenachne, Aleman grass*, bellyache bush, para grass, mission grass, annual pennisetum, Tully grass, siratro

* not currently found in KNP

10.1.2 Main threats

- Feral animals disturbance – increase risk
- Fire grass cycle
- Wide range weeds outside KNP boundary – eg gamba, olive, mission, mimosa
- People - vehicle and people traffic into Park
- Resourcing inadequate
- Climate change

10.1.3 Challenges and solutions

- Set clear and measurable targets
- Monitoring data not sufficient to inform management planning
- Need to improve / rethink way gather information (not just weed teams, but TOs, contractors, councils etc)
- Make data collection spatially explicit and easy to collect/upload

[1] Environmental Research Institute of the Supervising Scientist, GPO Box 461 Darwin NT 0801
[2] Earth Water Life Sciences, PO Box 39443, Winnellie, Northern Territory, Australia 0821

- Data access (mapping, best practice, R&D)
- Improve coordination / communication within KNP
- Recognised resourcing required varies across habitats eg weed control in wetlands – airboats: eg timing of control
- Staff have limited skills and expertise to develop databases and collate information – outsource the work
- Update weed management strategy (new spp, new tools – WRM, roles and responsibilities)
- Development of a joint weed management strategy with all stakeholders in the Kakadu region
- Collection and Distribution of weed information
- Raising community awareness of weeds and threat posed
- Rework NT weed risk assessments for KNP to reflect regional differences
- Range of stakeholders need to be consulted and engaged
- Time must be made available for field staff talk to people and look for incursions

10.1.4 Options

- Widespread high density weeds (eg para grass) – minimise impact and containment
- Widespread low density (eg olive hymenachne) – detection and containment
- Potentially invasive with limited distributions (eg Jabiru gardens) – Weed Risk Assessment and eradication

10.1.5 Bininj perspectives

- Improve communication with TOs (all stages – planning, progress, outcomes - OWNERSHIP)
- Need to counter impression nothing comes from being part of decision making process
- Staff out on country talking to people is important – gathering information eg weed outbreaks – feedback / engagement
- Perception that TO priorities are not always reflected in priority lists (part communication, part process)
- Weeds recognised as a big problem – changed landscape, reduced bush tucker availability
- Too much talk not enough visible action

10.1.6 Key knowledge gaps

- Update weed management strategy
- Further improve mapping and detection
- Adopt NT Government Weed Risk Assessment tool
- Develop realistic thresholds and targets based on risk
- Integrated and novel control methods

- How to engage community including Bininj (Traditional knowledge)
- Weed ecology – key species
- Weed Risk Management approaches
- Databasing/GIS

  Need good spatial data essential for decision making with regard to:

  - Defining distributions
  - Rates of spread
  - Location
  - Planning control
  - Auditing success of control
  - Long term monitoring
  - Communication

10.2 Paper

10.2.1 Introduction

Kakadu National Park currently has about 120+ species of invasive plants, representing about 7.8% of the total flora. However, this is relatively low when compared with an average of 21% in other Australian conservation areas (Lonsdale 1992). The number of alien plant species in Kakadu has increased at the rate of 1.6 species per year since 1948, and is expected to continue at an increased rate as a result of increasing tourism and development (Cowie & Werner 1993). A relatively high proportion of the 120+ species, are found in areas of intense human activity such as the Energy Resources of Australia (ERA Ltd) leases (71 species) and the township of Jabiru (55 species). Other areas such as Mudginberri, Munmarlary, Old Kapalga Ruins, Nourlangie Camp, Cooinda Motel, El Sherana, and Old Goodparla for example also have large numbers of weed species and were originally given high priority for control (Brock & Cowie 1992).

For an area like Kakadu, apart from the problems of controlling existing weeds, there is the seemingly inexorable advance of major potential invaders (Storrs 1996). Kakadu National Park management currently spend about $1.2 million on weed prevention and control and a large proportion of this budget is spent on controlling already widespread weeds such as mimosa and perennial grassy weeds. Such resource commitment does generally not occur in areas surrounding the Park and, unfortunately, as weeds do not recognise land tenure boundaries the 'battle' against weeds within and around the Park will continue in perpetuity and will require ever increasing reinforcements.

Many weed species already present in KNP have the potential to cause dramatic changes at the landscape scale. For example, the mimosa experience elsewhere in the Top End has seen tens of thousands of hectares of wetland converted to shrubland with a consequent crash in biodiversity and greatly reduced access for cultural, recreational and pastoral endeavours. Para grass is spreading on floodplains of the Top End including those of KNP, and its preferred habitat is that of the native *Oryza* spp (wild rice) which is an essential nesting and food resource for the iconic magpie goose.

In general, the extent of weed invasion has been described for some species although often incompletely. In many instances, vital information on the ecological changes wrought by these species is often confined to a few isolated studies or to anecdotal evidence. Economic analyses of the losses caused by weed species are uncommon, and studies on the social and cultural impacts of weeds have not generally been done (Finlayson & Spiers 1999).

The objective of this paper is to look at several broad issues surrounding weed management in Kakadu National Park including, threats, management challenges such as costs, thresholds, monitoring, mapping and collaboration and to discuss key knowledge gaps.

10.2.2 Main threats

Storrs (1996) lists 15 species of high priority weeds that exist in small to large infestations and which are capable of significant impacts:

Andropogon gayanus [gamba grass]

Brachiaria mutica [para grass]

Calopogonium mucunoides [calopo]

Calotropis procera [rubber bush]

Cassia fistula [golden shower tree]

Crotalaria goreensis [gambia pea/rattle pod]

Delonix regia [poinciana]

Jatropha gossypifolia [bellyache bush/nut]

Leucaena leucocephala [coffee bush]

Mimosa pigra [mimosa]

Parkinsonia aculeata [parkinsonia]

Pennisetum polystachion [mission grass]

Salvinia molesta [salvinia]

Senna alata [candle bush]

Xanthium occidentale [noogooro burr]

Other high priority KNP species identified more recently include:

Eichhornia crassipes [water hyacinth]*

Hymenachne amplexicaulis [olive hymenachne]

Echinochloa polystachya [aleman grass]*

Pennisetum pedicillatum [annual pennisetum]

Brachiaria humidicola [tully grass]

Macroptilium atropurpureum [siratro]

* not currently found in KNP

It is beyond the scope of this forum to discuss in detail the life history, biology, ecology and impacts of all the species listed above. Such information is readily available in a variety of literature. As mentioned, species such as mimosa, para grass and salvinia have the capacity to impact at the landscape scale on the floodplains of Kakadu and, if left unchecked, will ultimately dominate this important habitat, many of which are Ramsar listed. A further and unquantified impact of species such as mimosa and para grass is their ability to alter hydrological regimes on floodplains and waterbodies because their structure is more dense than the native vegetation they displace. This leads to increased sedimentation with subsequent shoaling and, in some cases, complete elimination of water bodies (Braithwaite et al 1989). The dense mats formed by salvinia can have similar effects via physical clogging of water pathways. Many weed species facilitate also fires of increased intensity and/or frequency (eg Rossiter et al 2003, 2004, Douglas & O'Connor 2004).

Whilst there are some management strategies in place for some of the species listed above, many are either not controlled or at the least are only controlled opportunistically when time and resources allow. This is not to criticise Park managers and on-ground staff as they do as much as they can within current resource allocations. When allocating resources it cannot always be assumed that the current level of commitment will be sufficient to alleviate the threat. One such example could be that of mimosa where the annual budget of $500K has been sufficient to keep mimosa from establishing within the Park. A potential re-assessment of this commitment could occur if mimosa establishment was to 'out pace' the monitoring and surveillance efforts. For example, there was concern following the recent 2006–07 extreme wet season floods that if the seeds of a few undiscovered plants were dispersed at that time then they would be carried far greater distances and possibly into previously unsurveyed areas/habitats than would normally occur. This could make it difficult to detect new incursions and, if the same scenario was repeated the following year, then the effect could be greatly multiplied (Buck Salau pers comm).

10.2.3 Key management challenges

10.2.3.1 Regional and external pressures

Ground disturbance (ie the removal of native vegetation) is considered to be the prime cause of weed establishment. Fortunately for KNP, ground disturbance is relatively low compared to some other land tenures, although much has already occurred through mining, pastoralism, tourism and feral animals. Kakadu is still subject to large scale movements of people, vehicles, machinery and boats and these weed spreading vectors are always going to be present. Since the removal of feral buffalo there has been a considerable rise in pig densities and subsequent ground disturbance (Bayliss et al 2006) (Figure 1). In a recent study at Boggy Plain there was a positive correlation between the % cover of pig ground disturbance and the number and % cover of weed species (P Bayliss pers comm). Not only does the ground disturbance facilitate weed establishment, the movements of pigs through weed infestations and into important riparian and monsoon jungle habitats is also cause for concern.

Grassy weeds such as mission, annual pennisetum and gamba are well known for altering fire regimes to more intense and frequent fires with the ultimate outcome of converting savanna woodlands to grassland via the destruction of trees and shrubs that would usually be resistant to natural fires. This 'grass-fire cycle' is currently being investigated (eg Rossiter et al 2003, 2004) and is occurring across vast areas of the Top End. Para grass is also capable of increasing fire intensity on the floodplain and in fringing forests such as paperbarks (Douglas & O'Connor 2004).

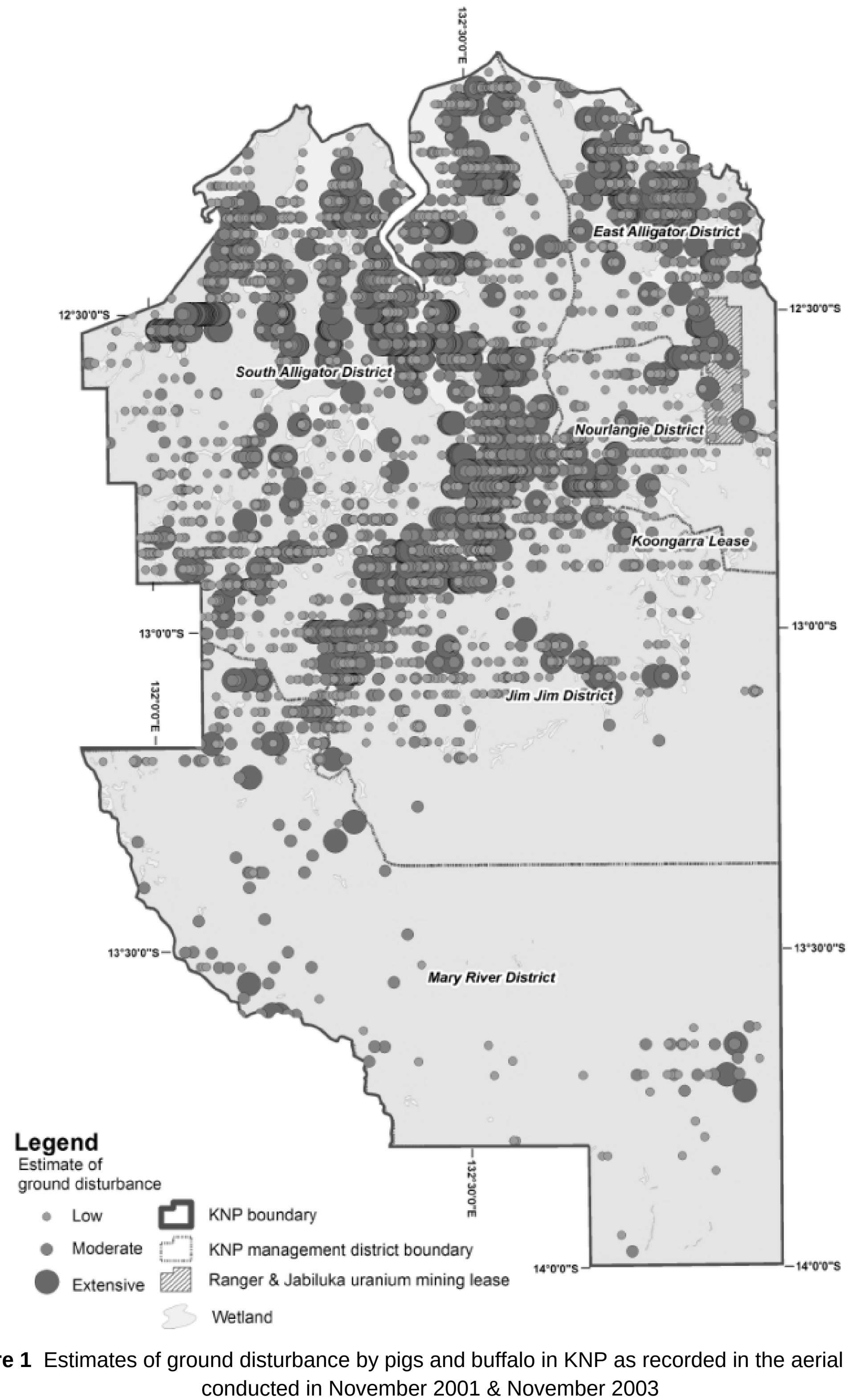

Figure 1 Estimates of ground disturbance by pigs and buffalo in KNP as recorded in the aerial survey conducted in November 2001 & November 2003

A wide range of weeds exist outside of the Park boundaries (eg mimosa, mission and gamba grass and olive hymenachne) and many of these are often at different densities to that in the Park. The challenge for Park managers, therefore, is to not only control weeds within the Park but also to combat weeds in neighbouring areas. Whilst this is not 'technically' the Park managers' responsibility, it is however, essential that it occurs in terms of a weed management strategy. Unfortunately stakeholders outside of the Park often lack the resources or even the will for weed management.[3]

The issue of climate change in relation to the future spread of weeds is shrouded with uncertainty and may affect different species in different ways. There is evidence to suggest that major changes in vegetation composition will come through shifts in rainfall pattern, temperature and increased runoff distribution. In conjunction with the 'CO_2 fertilisation effect' resulting from elevated CO_2 levels, a number of authors have stated that this will most likely favour the establishment of woody vegetation and encroachment of woody shrubs in many areas (eg Hughes 2003). The direct CO_2 fertilisation effect may lead to increased growth, particularly during periods of reduced soil moisture (Campbell et al 1996). A marked increase in woody biomass ('vegetation thickening') at the landscape scale has been reported for a wide variety of arid and semi-arid environments, as well as tropical eucalypt savannas (Bowman et al 2001) and open woodlands (Archer et al 1995, Henry et al 2002). Berry and Roderick (2002) described landscapes in terms of the abundance of three different functional types of leaves. Using continental scale maps of past and present vegetation, they estimated the change in proportion of the three leaf types that has occurred as a result of increased CO_2, as opposed to land-use change. They concluded that increasing CO_2 would have exacerbated the woody weed problem. In the longer term, this may have implications for weeds such as mimosa, parkinsonia, bellyache bush and rubber bush for example.

The anticipated increased incidence of extreme events is likely to increase the disturbance of natural systems and render them more vulnerable to invasion by exotic species by increasing the stress on established vegetation (CSIRO 2001). Increases in flood frequency and intensity could possible facilitate the spread of those weed species that rely on floodwaters for the distribution of seeds and/or vegetative material. A rise in average maximum temperatures and the frequency of 'hotter' days may promote the proliferation of wildfires, which may be exacerbated by those species mentioned earlier related to the grass-fire cycle. Climate induced sea-level rises may actually reduce suitable habitat for weeds such as mimosa, para grass and salvinia in low-lying coastal floodplain areas by increasing salinity beyond their environmental ranges (Dames & Moore International 1990). Any changes in weed distribution and abundance resulting from climate change will most likely be undetectable in the short term (maybe even up to 50 yrs), given the myriad of other influencing factors. However, monitoring over greater time-scales may detect changes at the landscape scale.

10.2.3.2 Clear and measurable targets

For many of Kakadu's weed species, eradication is not an option as the resources required would be prohibitive. Figures 2, 3, 4 and 5 show control cost curves for para grass, mimosa (2 curves) and rubber bush respectively. Note the dramatic increase in cost associated with locating and/or removing the weed as the last remnants of the infestation persist[4]. Rejmanek & Pitcairn 2002, using data for weed infestations in California, show that eradication of exotic weed infestations smaller than one hectare is usually possible. In addition, about 1/3 of infestations between 1 ha and 100 ha and 1/4 of infestations between 101 and 1000 ha have been eradicated. With a realistic amount of resources, it is very unlikely that infestations larger than 1000 ha can be eradicated.

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[3] Many grassy weeds of conservation areas are deemed a valuable resource on pastoral properties for livestock fodder, which is why they were initially introduced.

[4] A good analogy here is KNP's ~$500K per annum investment in the survey/prevention of mimosa incursions

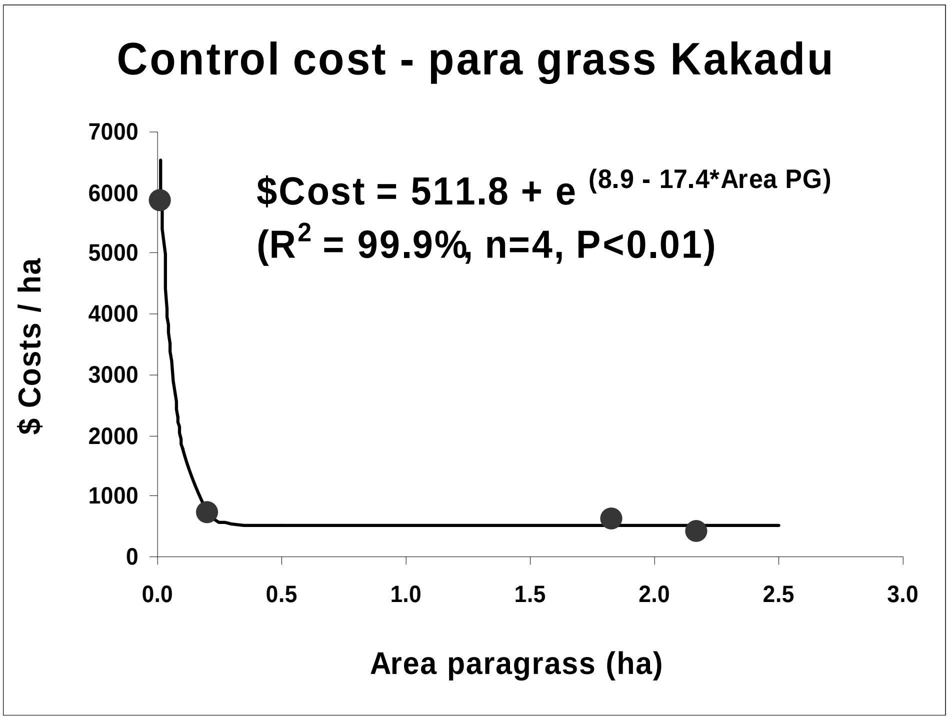

Figure 2 Control cost curve for para grass on Nourlangie Creek, South Alligator River, Kakadu National Park (1996–1997), showing a negative exponential relationship. Data provided by Kakadu staff.

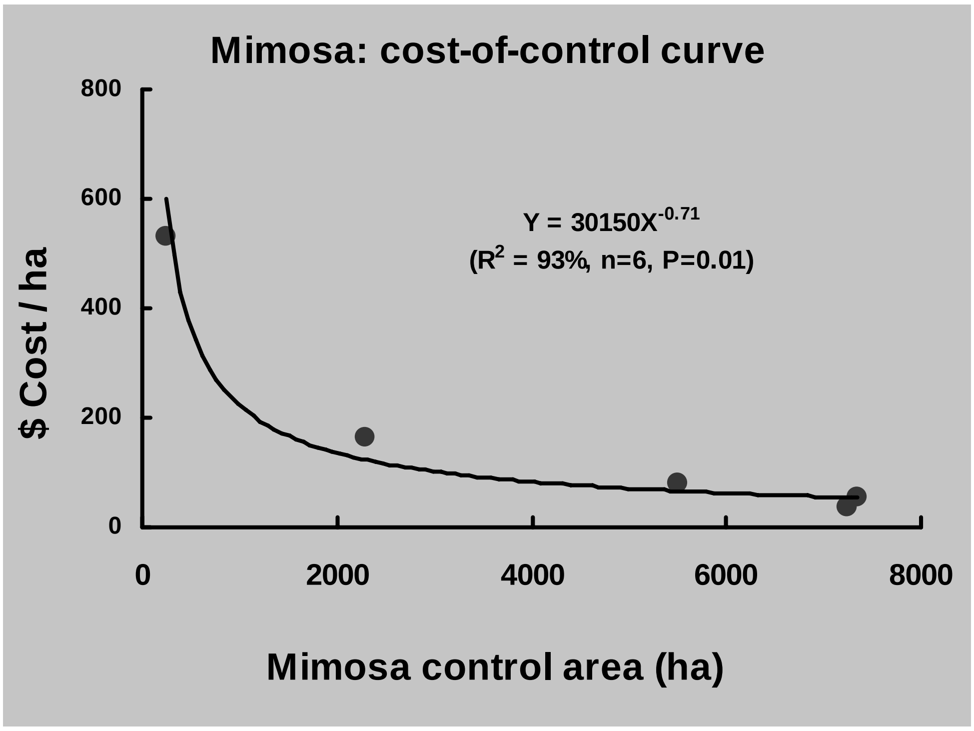

Figure 3 Estimated control cost ($) for large infestations of mimosa on the Gunbalanya floodplain, west Arnhem Land. Operational costs only, and excludes salary and salary related on-costs, and large capital items. Derived from NT Department of Primary Industry, Fisheries annual reports 1991–1997.

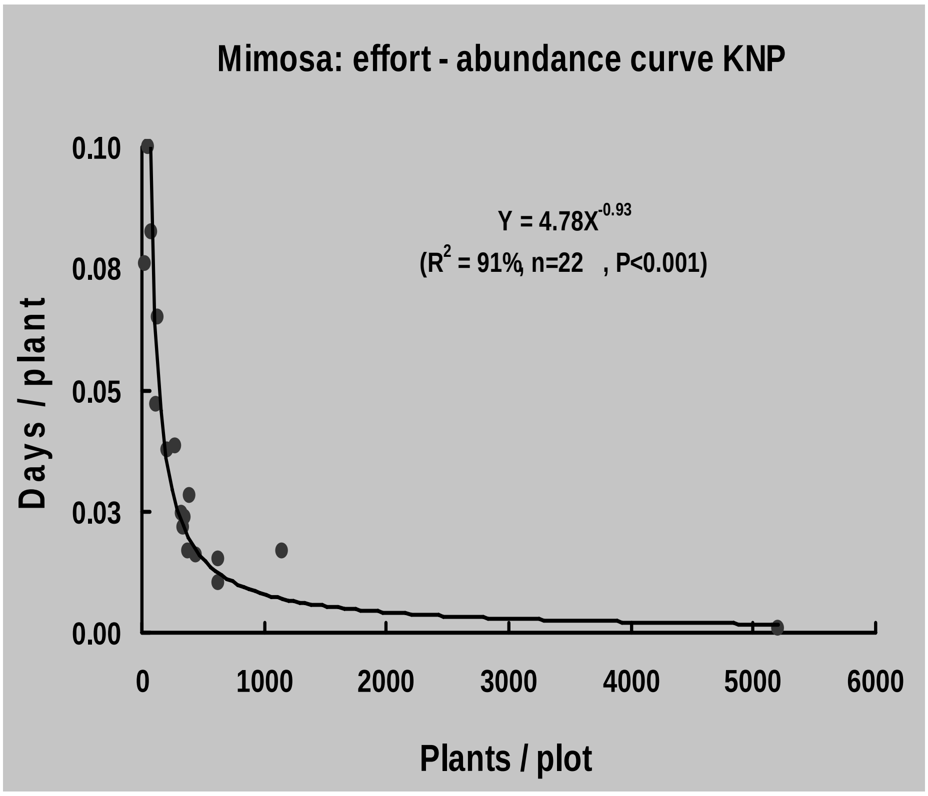

Figure 4 Control effort - abundance curve for mimosa survey and control in KNP. Data from the KNP mimosa database.

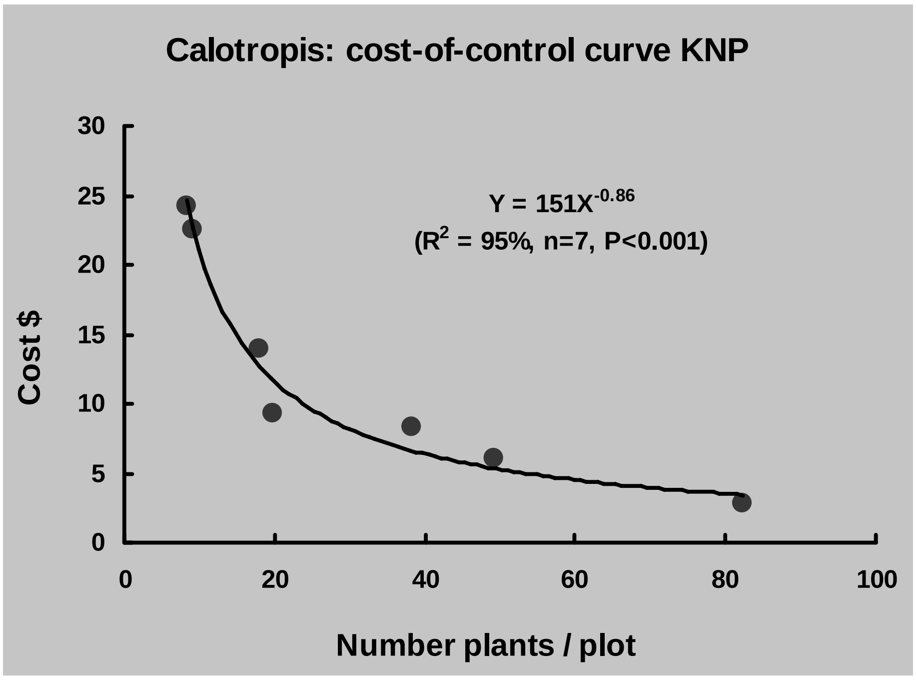

Figure 5 Cost-of-control curve ($ per plot) for rubber bush in the upper South Alligator Valley. Data provided by Kakadu staff.

Weed management strategies usually incorporate threshold or target levels that are agreed on and deemed by stakeholders as an acceptable level of impact. On the Magela floodplain, data obtained from sample plots in 2003 show that the percentage of native vegetation (eg wild rice, *Eleocharis*, *Hymenachne*, open water/lilies & *Leersia*) 'lost' to para grass rapidly increased with increasing weed cover and, importantly, that there was a ‘threshold’ effect for each plant group (Figure 6). Hence, for most floodplain plants measurable impacts did not occur until para grass reached 15–20% cover, suggesting that this extent may represent a pragmatic, cost-effective and justifiable control target (Bayliss et al 2006). The cost-curve for para grass shows that a 15–20% control target would avoid exponentially increasing control costs generally associated with unachievable eradication objectives, or cost-prohibitive ‘trace level’ objectives. However, this reasoning may not apply to mimosa because of its massive seed set.

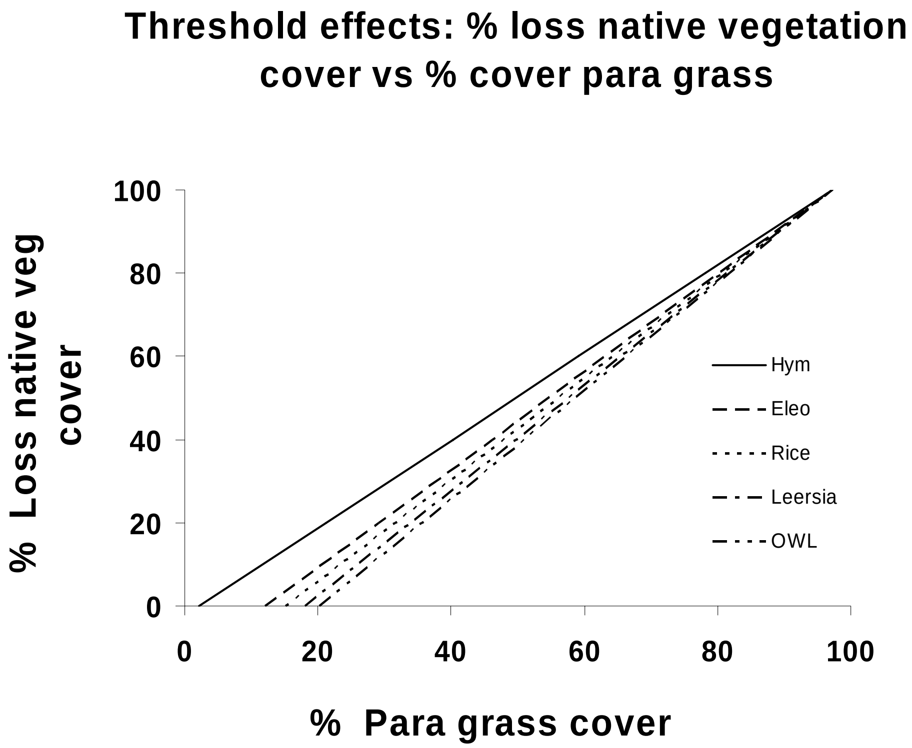

Figure 6 Relationship between loss of native vegetation cover (%) of five key wetland plants and increasing cover of para grass

The setting of clear and realistic targets ensures that available resources are allocated in such a way that the target is not only achievable but also sustainable in terms of follow up control. Many weed species have the ability to regrow from the seed bank for years, sometimes decades, and this must be taken into account when embarking on control programs. The follow up control usually far exceeds the expense of the initial mass reduction of the infestation. Furthermore, for some species, additional management expenses maybe incurred if the weed has somehow suppressed the regrowth of native vegetation either via chemical inhibition or habitat modification. One such case is para grass, where it is believed that the higher temperatures needed to break the dormancy mechanism of *Oryza* seeds for example, are not achievable beneath the dense shading structure and greater litter volume of para grass (Wurm et al 2006), thus, the *Oryza* seedbank maybe entirely depleted in areas where para grass has been present for many years. In this scenario, even once para grass is removed, active reseeding or replanting may be required to re-establish *Oryza*. This single factor could greatly increase any cost-of-control projections.

10.2.3.3 Control and monitoring data

Following on from the above issues, the management plan can only be developed through research on the impact of the species to determine the acceptable target/threshold and more importantly, using quantitative data on the control costs including factors such as volume and type of herbicides used, area and density class of weed, equipment used, total staff travel and operation time, and an assessment of the success of the control operation. There is some data available for species such as mimosa and para grass, and this has enabled cost of control and/or effort-abundance models to be developed, which identify the potential costs for reaching and maintaining *a priori* targets. For example, recently completed simulations for cost of chemical control of para grass on Magela floodplain, using Park ground control data for the Nourlangie system, suggests that a containment and 20% cover target reduction strategy would initially cost $1.8 million and $400K–$500K thereafter (maintenance control). These estimated annual maintenance costs are similar to annual maintenance costs of mimosa control on the Park. However, it should be stressed that these are 'first-cut' estimates only and can be refined with the availability of further data (Bayliss et al in prep.).

10.2.3.4 Gathering information and mapping

Although data management systems used by Parks are improving in relation to gathering weed information, there is still a long way to go. The mimosa team, and more recently the grassy weeds team, have been established for a specific purpose and therefore have been given clear guidelines on data recording for monitoring the extent of infestations and effort/costs expended This not always achievable across the board for all staff involved in weed control. Staff often lacked the skills and expertise to develop databases and collate information in a manner useful for management assessment purposes. Sophisticated field data collection techniques exist employing GPS and palm-top computers that enable faster and more accurate recording of infestation location, size, mapping and the assessment of control success. Data can be readily downloaded in a useable form back at the office and, databases, maps and GIS projects can be updated on a regular basis. Data collection needs to be spatially explicit and easy to collect and upload. If it is not possible to achieve this with the current data management framework used by Parks', then the outsourcing of such expertise may be necessary.

10.2.3.5 Empowering others – shared responsibility

All stakeholders need to be concerned about, and participate in, weed issues within KNP. The responsibility should not be viewed as being that of the Park managers alone. Any weed management strategy should be developed with all stakeholders in the Kakadu region. Weeds ultimately affect all stakeholders, be it from a mining perspective, tourism or recreational land use, conservation and biodiversity or traditional cultural uses of the land. The Bininj want to be and need to be involved in all weed issues. Indeed an aim from the KNP 5th plan of management states:

> Through working with Bininj, Park values are protected by strategic management of weeds, prevention of invasion of new species, and increased understanding of weed management issues among Park residents, neighbours and visitors.

Communication with TOs is essential for all stages of weed management, including, planning, process, progress and outcomes. This will provide a sense of ownership of the issues and active engagement compared to being relegated the role of passive observer of the processes. The Bininj spend more time on country and travel to more places than most others in the Park, and they know when something looks out of place on their land. Empowered with this innate weed identification and other knowledge they can be a significant force in the detection of weed outbreaks. Hand in hand with this is the need for feedback and engagement once the incursion has been located. Such measures help to alleviate the perception that there is more talk than action with respect to weeds. The priorities for control of weed species may not always be the same for the Bininj as for other stakeholders. For example, those weeds that reduce availability of and/or access to bush tucker will have a higher priority than other species. In some cases, species such as rosella and wild passionfruit are viewed as resource and are deemed as useful.

Energy Resources of Australia (ERA Ltd) have committed considerable resources to weed issues both on and off their leases (Jabiluka & Ranger). They are sharing their research and management knowledge of weeds at many levels, in addition to reducing the density and spread of on-site weeds. This commitment needs to continue, especially as the company enters the rehabilitation phase of their operations in the near future, with on- and off-site weeds having the potential to impede ecosystem establishment on the rehabilitated landform.

Jabiru Town Council and residents need to be actively engaged given the potential for the Township being a significant source of a variety of weeds and also the focus point of a large volume of travellers. Potential problem weeds in the town need to be identified and eradicated before they have the chance to spread. A multi institutional program knows as the Jabiru Weedy Time Bomb has commenced in 2007 (see NHT envirofund application – 'Threat to western Arnhem Land: the Jabiru weedy time bomb'). This project aims to eradicate at least 10 potentially invasive species with limited distributions in the Jabiru township before they become widespread and established in the surrounding KNP.

The old saying 'prevention is better than cure' has never been more apt than when applied to the issue of weeds. Relatively low-cost prevention measures can save millions of dollars in the long term. For example, the mimosa control program to prevent incursions may seem at first pass expensive, yet it is a very sound investment given the control costs already spent (and yet to be allocated) for areas elsewhere. Public awareness procedures targeting groups and individuals including tourism operators, contractors, residents and recreational Park users (campers, bushwalkers and fishermen) have been implemented by Park managers and needs to be re-emphasised and updated as weed species and their distributions evolve.

10.2.3.6 Different species, different risk, different priorities, different approach

Risk is a combination of the effects (impacts) and the exposure (extent) (see section 3, Ecological Risk Assessment by Peter Bayliss). A weed maybe widespread but its impacts may be relatively minor, meaning the risk is considered low (eg passionfruit vine). Likewise, a species may have the potential for significant impacts, but is currently limited in its density and/or distribution (eg olive hymenachne). Knowledge of these two factors is essential when developing a management strategy and prioritising for control. Potentially invasive 'sleeper' weeds that have potential for significant impacts, but with a very restricted distribution or are yet to escape from urban areas for example, should be given a high priority as they may be easily identified and eradicated with relatively little effort. Species such as olive hymenachne, which at this stage has a relatively low density on the Park, may also be detected and contained before they become a serious problem. Other species, such as para grass, that have high densities with wide distributions need to be assessed within the context of the available resources. Minimising impact is preferred but not always feasible, so at the very least, satellite infestations need to be targeted to prevent further local spread and, if possible, quarantine measures implemented to prevent more regional spread, although unfortunately some species are spread by wildlife including birds, thus no amount of quarantine or fencing will suffice.

10.2.4 Key knowledge gaps

10.2.4.1 Mapping, databases and GIS information

Although continual improvements are being made, the detailed mapping of weed locations and patch sizes, and the incorporation of this information into databases and GIS is sadly lacking for many KNP species. Two major alien plant surveys have been undertaken in the Park by Cowie and Werner (1987, 1988) and Brock and Cowie (1992). Unfortunately, despite recommendations, such broad scale weed surveys have not been repeated. District staff *do* survey for weeds, though often their time and resources limit them to the more noticeable and/or problem weeds and often in smaller areas than they would like.

It is difficult to overemphasise the importance of mapping weeds and data storage. Accurate and regularly updated maps and databases enable the manager to:

- Assess the size/extent of the problem
- Detect satellite infestations (if possible given the method)
- Determine rates of spread
- Divide the problem into manageable portions
- Identify the threat to significant habitats
- Audit and monitor the success of control programs
- Communicate results in a spatially explicit, comprehensible way

Recent investigations by the Environmental Research Institute of the Supervising Scientist (eriss) into the extent of para grass on the Magela floodplain are testament to this. Earlier work put the extent of para grass at approximately 422 ha in 1996. Using QuickBird satellite imagery, the extent is now estimated to be at least 1250 ha of 100% cover representing an average spread rate of about 14% per annum (Walden et al in prep.). This information has facilitated the bio-economic modelling scenarios outlined in section 9.2.2.3.3 above to put a dollar Figure of reducing and maintaining that reduction to the chosen target level. Other weed maps are emerging and it is anticipated that, in the future, similar maps will be able to yield comparable information depending on the ability of the map source to detect the species accurately. Whilst there is still much work to be done in this area, initial results are promising.

10.2.4.2 Weed ecology

Knowing how a weed behaves in different environments and knowledge of its habitat preferences are fundamental when developing a management strategy. There are varying levels of this information for various species with most of the research coming from outside of the Park. Nevertheless, in most cases such knowledge is still applicable given the similarity of preferred habitats. There is also much anecdotal corporate knowledge that needs to be captured because most of it exists in the experiences of staff and is rarely documented. Whilst the Bininj may or may not know the specifics of invasive weeds on their country, they do know the specifics of the country and how similar species behave. Thus it is essential to use this traditional knowledge and engage the Bininj as much as possible. We will never know all things about all weeds, so priorities for research directions need to be established for key species and the work shared amongst all stakeholders and other agencies with relevant expertise.

Some of the important factors include:

- the flowering ‘window’ and peak flowering times
- time to maturation

- the number of seeds, germination factors, seed germination period and the longevity of seeds in the seed bank
- invasion rates and key pathways
- hydroperiod and inundation levels
- local topography, soil type, soil moisture and pH
- nutrient requirements
- salinity tolerance
- associated plant communities and competition
- shade tolerance
- response to fire
- allelopathic capabilities[5]
- potential pathogens

Habitat suitability modelling (HSM) is a powerful tool that can assist managers to target specific areas/habitats for weed control. This has the benefit of reducing the resources required to search for and destroy weeds. Some weeds are generalists but many have specific niches that can be identified, quantified and targeted. Much of this information is also relevant for cost-of –control modelling.

10.2.4.3 Weed risk management approaches

Some of these issues are discussed in the above sections. For some species we have an idea of what the risks are, where to start and what approach to take. That is, there is sufficient information, anecdotal or otherwise to know the impacts, the approximate distribution and the method of control. So why don't we just go and get rid of them? The answer is a 'no brainer' – because resources are always limiting and there are rarely enough for part of, let alone the whole, problem. This is why we need to determine realistic thresholds and targets based on the ecological risk, and from there estimate what it is going to cost to achieve and maintain those targets. We need more knowledge also on how to improve on-ground operational control methods including testing innovative methods in large plot experiments and/or via adaptive management (learning by doing). Although much knowledge exists there is still much to learn about choice of herbicides, wetting agents, application rates, timing of application and follow-up application to name a few. Other methods such as fire, drowning, mulching, slashing and competition need to be explored as they have the potential to be cost effective. For this, we need to know more about those factors outlined in the above section. As time goes by, new weeds emerge, research progresses, technology improves and priorities may even change, so maybe it's time to update the KNP weed management strategy which is now nearly 12 years old.

10.2.5 Conclusions and recommendations

- Update the KNP weed management strategy
- Further improve mapping and detection

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5 The weeds ability to produce chemicals or otherwise modify habitat so that growth of other vegetation is inhibited.

- Adopt the NT Government Weed Risk Assessment tool
- Develop realistic thresholds and targets based on risk
- Employ integrated and novel control methods
- How to engage the community including Bininj
- How to find sufficient resources for ever growing weed problems

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11 Climate change – The status of climate change research in the Kakadu landscape context

R Bartolo[1], R Wasson[2], E Valentine[2], S Cleland[3],
P Bayliss[1] & S Winderlich[4]

11.1 Focus summary

11.1.1 Current knowledge in relation to KNP's management plan objectives

- KNP will be subject to the impacts of climate change including sea level rise, increase in temperature, increases in extreme events such as hot spells and storm surges, possible increase in tropical cyclone intensity and changes to localised rainfall patterns.
- The coastal environment of KNP is dynamic and habitat change has occurred in the past due to fluctuations in sea level. The freshwater floodplains are young in age.
- Impacts of climate change will affect: Bininj use of natural and cultural resources; fire regimes; flood inundation patterns in freshwater systems; location of biodiversity; and availability of freshwater to both the natural environment and people.

11.1.2 Main threats to landscape health in KNP

- Saltwater inundation of freshwater coastal environments due to sea level rise and storm surge events.
- Response of mangrove communities to rising sea level.
- More intensive fire regimes may eventuate due to hotter dry seasons (extreme event hot spells) and these hot fires may result in decline of monsoon forest.

11.1.3 Management options

- Implementation of an integrated environmental research and monitoring program to underpin management decisions.
- Mitigation activities such as building suitable barrages located in strategic positions in order to protect freshwater environments from saline intrusion.
- Governance structure that enables the impacts of climate change within the region to be addressed, giving consideration to the connectivity of freshwater floodplain systems to the east and west of KNP's boundaries and to involvement of the key stakeholders within the region.

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1 Supervising Scientist Division, Department of the Environment, Water, Heritage and the Arts, Darwin NT.
2 Charles Darwin University, NT 0909.
3 Bureau of Meteorology, Darwin, NT.
4 Parks Australia North, Kakadu National Park, Jabiru NT.

- Identification of hazard and risk (within the natural environment, built environment, cultural and heritage, and environmental heath) and plans to minimise these hazards and risks.
- Strategic management of regional development that recognises the competing interests of stakeholders.
- Information management (that facilitates data acquisition and custodianship).

11.1.4 Key knowledge gaps

- A record of the wide range of stakeholder perceptions and values in management activities for climate change impacts. Also, the potential impacts to Bininj use of natural and cultural resources needs to be documented.
- The observed rainfall trends such as build up rainfall have not been studied in detail and the global models are not predicting what is occurring in the region.
- An economic value needs to be determined on the natural resources that are at risk from climate change impacts within KNP.
- Assessment of the ability of refugia to conserve freshwater habitat biodiversity in the past in the context of identifying refugia that may conserve the existing biodiversity in the future.
- The most significant gap in our current knowledge with respect to hydraulic changes in estuarine and river environments is the rate at which changes due to over bank flows evolve.
- The response of macro-tidal estuaries to sea-level rise within short time periods is only partially understood.
- Identification of plant communities (such as coastal monsoon forest) that may be susceptible to climate change impacts.

11.2 Paper

11.2.1 Climate change predictions in the Top End and Kakadu National Park

The most current projections for climate change relative to 1990 in the Top End of the Northern Territory are provided by Hennessy et al (2004). The projections are summarised as follows for Kakadu National Park:

11.2.1.1 Temperature

- Wet season average temperature (November–April) may increase in the range 0 to 1.5 º C by 2030 and 1–5.5 º C by 2070.
- Dry season average temperature (May–October) may increase in the range 1 to 2 º C by 2030 and 1–5.5 º C by 2070.
- In the context of the Northern Territory, the least warming is expected over the Top End.

11.2.1.2 Rainfall

- The projections indicate that there is little change in wet season rainfall (±8% by 2030 and ±20% by 2070).
- Dry season rainfall projections indicate that the region may become wetter during this season (-8% to +20% by 2030 and -20% to +60% by 2070).

- An increasing trend in summer rainfall has been observed over most of the NT since 1950, which has been strongest over the central and western Top End, where increases of the order of 50 mm per decade have been observed. See http://www.bom.gov.au/cgi-bin/silo/reg/cli_chg/trendmaps.cgi. This observed increasing trend has not been portrayed in some climate models, so engenders some uncertainty with respect to rainfall projections of the region.

11.2.1.3 Evaporation and moisture balance

- The ranges reported here are approximations from maps published in Hennessy et al (2004).
- Potential evaporation in the region generally increases.
  - Wet season potential evaporation may increase 1–4% by 2030, and 2–12% by 2070.
  - Dry season potential evaporation may increase 2–7% by 2030, and 4–20% by 2070.
- The moisture balance is expected to decline for the region.

  – In the wet season, the moisture balance is expected to decline 50–100 mm by 2030, and 25–320 mm by 2070, but has uncertainty related to the rainfall projections.

  – In the dry season, the moisture balance is expected to decline by up to 75 mm by 2030, and 50–250 mm by 2070.

11.2.1.4 Extreme temperature

- The average number of days over 35ºC at Oenpelli is expected to increase from the present (124 days) in the range of 128–196 days by 2030, and in the range of 167–320 days by 2070.
- The average number of 3–5 day hot spells over 35ºC at Oenpelli is expected to increase from the present (31) in the range of 33–53 hot spells by 2030, and in the range of 44–99 hot spells by 2070.
- The average number of days over 40ºC at Oenpelli is expected to increase from the present (1 day) in the range of 1–11 days by 2030, and in the range of 5–110 days by 2070.
- The average number of 3–5 day hot spells over 40ºC at Oenpelli is expected to increase from the present (0) up to 2 hot spells by 2030, and up to 29 hot spells by 2070.

11.2.1.5 Tropical cyclones

- It is believed that the intensity of tropical cyclones will increase due to physical changes induced by increases in sea surface temperatures.
- Frequency and paths of tropical cyclones are difficult to project into the future. This is in part due to inter-decadal variations associated with the El Niño-Southern Oscillation (ENSO) and the effect on tropical cyclone frequency. There is uncertainty on how ENSO will behave under predicted climate change scenarios.

11.2.1.6 Storm surge

- There have been no studies to date specifically detailing the effect of cyclone intensity on storm surge events in the Northern Territory. A study conducted in Cairns suggests that when cyclone intensity increases, a 1-in-100 year storm surge event becomes a 1-in-55 year event.
- The effect of sea level rise can reduce the return period of storm surge events.

11.2.2 Potential climate change impacts on Kakadu National Park

Bayliss et al (1997) present a framework for the assessment of coastal vulnerability due to predicted climate change and sea level rise in the Alligator Rivers Region. Table 1 provides a summary of the effects of climate change on environmental conditions and, the preliminary impacts. In this instance, the framework has been adapted to indicate the preliminary impacts that may be associated with changing biophysical processes. Inundation in Table 1 has been replaced with either flooding or saltwater intrusion as it is not a separate impact to either of these (as has been reported in Bayliss et al (1997), and vegetation loss has been included within habitat change.

Table 1 Preliminary climate change impacts associated with changes in biophysical processes (ie climate change effects on environmental conditions, after: Bayliss et al (1997, 11)

Climate change effects on environmental conditions	Preliminary Climate Change Impacts
Water level oscillation	Saltwater intrusion
(wave, swell and tide)	Erosion
	Habitat change
	Salt spray
	Storm surge
Hydrodynamics	Flooding
	Erosion
	Sedimentation
Subsidence	Saltwater intrusion
	Erosion
	Habitat change
	Storm surge
Sea Level Rise	Saltwater intrusion
	Storm surge
	Habitat change
	Flooding
Landforms	Sedimentation
(terrestrial, estuarine and coastal)	Habitat change
	Erosion
River flow	Habitat change
	Erosion
	Sedimentation
Ground water regime	Habitat change
Extreme climate events	Wind damage
	Saltwater intrusion
	Erosion
	Habitat change
	Storm surge
	Salt spray
	Flooding

Climate change effects on environmental conditions	Preliminary Climate Change Impacts
Estuarine hydrology	Erosion
	Sedimentation
Vegetative cover	Erosion
	Habitat change
	Sedimentation
Rainfall frequency and intensity	Flooding
	Erosion
	Sedimentation

11.2.2.1 Drivers for climate change impacts on Kakadu National Park

The two main drivers for climate change impacts on habitats within Kakadu National Park are sea level rise and an increase in frequency and intensity of extreme events. There are other drivers for climate change within the region but the impact of these are not as well understood because the environmental prehistory record for these factors either does not exist or has not been studied. Temperature is one such driver that will not only affect habitats but species biodiversity also through local and regional changes in distribution and abundance.

11.2.2.2 Sea level rise

The processes that influence sea level operate over many temporal scales within the geological time period (Church et al 2001), whilst also functioning across various spatial scales ranging from local through to global extents. The following factors contributing to sea level rise are presented in detail by Church et al (2001): ocean warming and ocean thermal expansion; changes in both the mass balance of glaciers and small ice caps, and the large ice sheets of Antarctica and Greenland; changes in terrestrial water storage runoff and evapotranspiration due to changing land use practices; localised increases in atmospheric pressure; and tectonic land movements.

Since the last glacial maximum (20 000 yrs ago) sea level has risen about 120 m with a rapid rise of an average rate of 10mm/yr between 15 000 and 6 000 yrs ago (Church et al 2001). The rate of sea level rise over the 20th century has been estimated at 1.7 +/-0.5 mm/yr, with higher rates of change observed during the latter parts of the century. (Bindoff et al 2007). Attribution studies have yet to fully explain all contributions to this rise (Bindoff et al 2007). Projected globally averaged sea level rise at the end of 2100 is in the range 0.18–0.59 m. This range represents the model-based projections over the six Special Report on Emission Scenarios (SRES) but excludes uncertainties in carbon-cycle feedbacks or ice flow processes because a basis in published literature is lacking (Meehl et al 2007). However, the projections take into account contributions from thermal expansion and a small contribution from land ice.

The net relative sea level trends at the Darwin monitoring station for the Australian Baseline Sea Level Monitoring Project is + 6.6 mm/year. This trend in sea level change may just be a measure of decadal variability as the project has been running less than two decades. Hence, trends due to anthropogenic climate change are yet to be attributed (National Tidal Centre, Bureau of Meteorology, 2007).

11.2.2.3 Extreme events

The effect of tropical cyclones on sea level has been demonstrated through the Australian Baseline Sea Level Monitoring Project. On 3 March, 2007, the sea level surged to 0.2 m above the predicted tide due to Tropical Cyclone George (National Tidal Centre, Bureau of Meteorology, 2007). During Tropical Cyclone Winsome in 2001, sea level rose to 1.3 m above the Highest Astronomical Tide at Groote Eylandt (National Tidal Centre, Bureau of Meteorology, 2007).

A cursory examination of tropical cyclone and surge data, and the link to saltwater intrusion in the Alligators River Region, has been conducted by Winn et al (2006). Over an 86 year period (1912–1998) 82 cyclones passed through the region. Between 1975–1991 there was comparatively less cyclone activity and, when examined against landscape change due to saline intrusion, cyclones may not be a major influence.

11.2.3 Habitats and potential impacts

Habitats that will be impacted by climate change in the region include freshwater wetlands, mangroves, monsoon forest, riparian communities, beaches and streams (hydrology) (Bayliss et al 1997). These habitats within Kakadu National Park that are at risk of climate change impacts are shown in Figure 1.

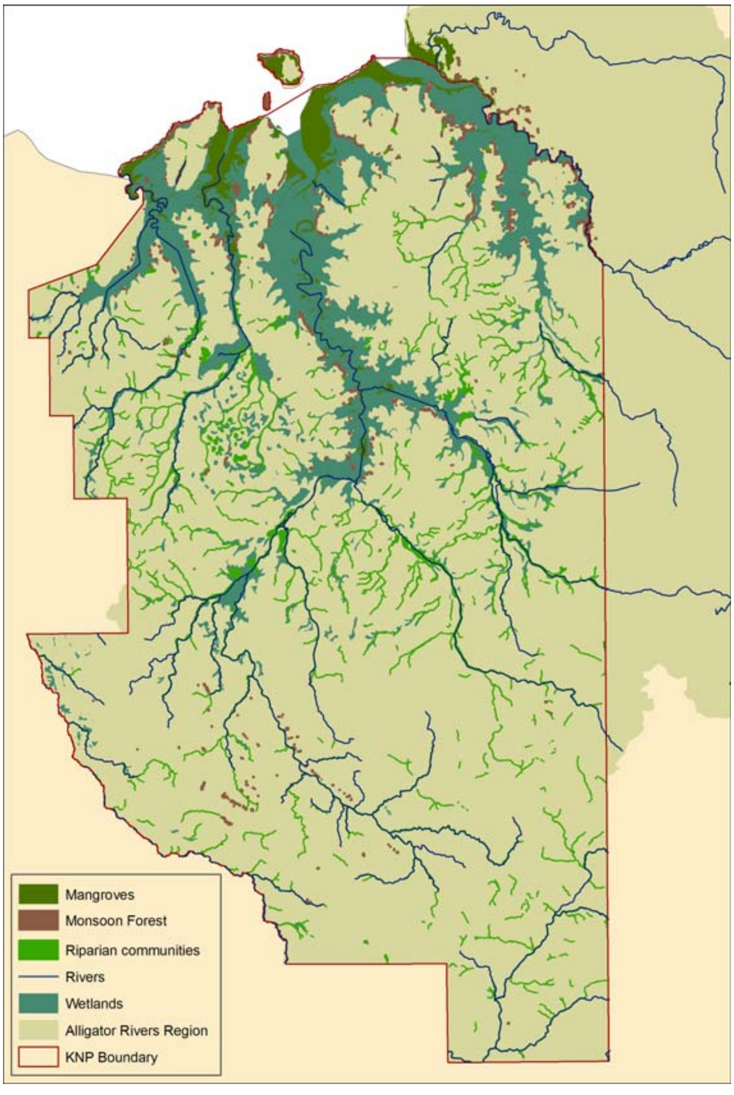

Figure 1 Habitats sensitive to climate change impacts within Kakadu National Park

11.2.3.1 Coastal wetland vulnerability to sea level rise

The extent to which the freshwater wetlands of Kakadu will be impacted by climate change is highly uncertain. These wetlands are vulnerable to sea level rise because they are low-lying, being situated within 0.2–1.2m of High Water Level (Hare 2003). Hennessy et al (2007:518), citing a source from Hare (2003), states that by 2050 it can be 'assumed' there will be a loss of 80% of freshwater wetlands in Kakadu for a 30 cm rise in sea level. Based on Bayliss et al (1997) 175 587 ha of coastal wetlands within Kakadu National Park may be affected by sea level rise (refer to Figure 2). This equates to 66% of the total coastal wetland area within the park boundary. The coastal wetland types (listed in Table 2) have been defined using the Geoscience Australia TOPO 250K GEODATA Version 3 spatial data. When the freshwater wetland types (Area subject to inundation and swamps) are extracted, based on Bayliss et al (1997) 72% of the freshwater wetland habitat within Kakadu may be affected by sea level rise impacts.

For a 1–2ºC increase in temperature, Hare (2003) predicts a 50% loss of Kakadu's wetlands, and a complete loss of wetlands for a 2–3ºC increase.

The environmental prehistory of habitat change reveals the response of habitats to sea level rise in the past, and provides us with an insight into how habitats may respond in the future (Woodroffe 1990).

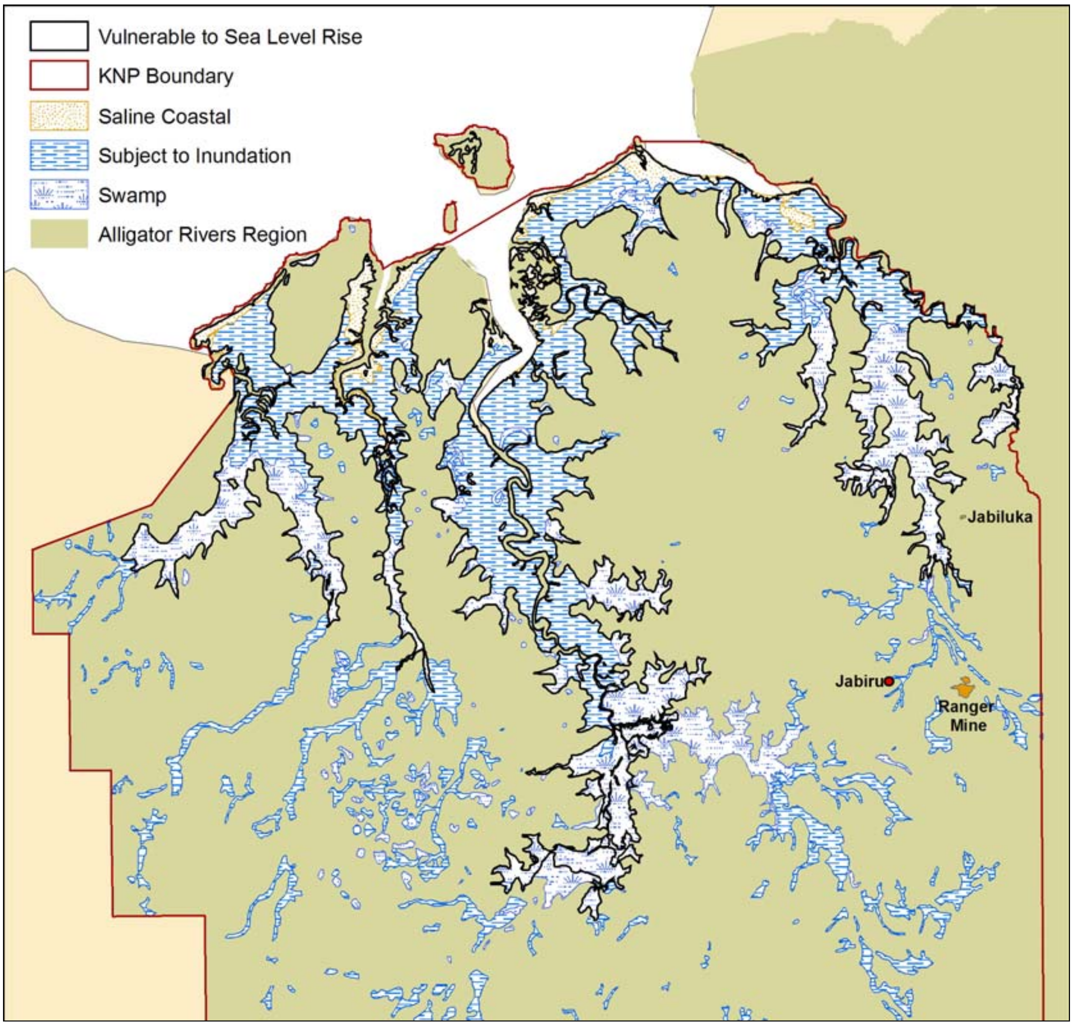

Figure 2 Wetland habitats at risk of salt water inundation due to sea level rise (after Bayliss et al 1997)

Table 2 Preliminary climate change impacts associated with biophysical change processes (climate change effects on environmental conditions (after Bayliss et al 1997, 11)

Coastal Wetland Type	Area (ha)	Freshwater Wetland Type	Total Area (ha)	Area Vulnerable to Sea Level Rise (ha)	% of Freshwater Habitat Vulnerable
Mangrove	8 579	Floodplain (area subject to inundation)	157 684	96 190	61%
Saline coastal flat	12 819	Swamp	86 479	80 406	93%
Floodplain (area subject to inundation)	157 684				
Swamp	86 479				
Total	**265 561**		**244 163**	**176 596**	**72%**

11.2.3.2 Hydraulic changes in estuarine and river environments

The South Alligator River experiences a spring tidal range of up to 6 m at the mouth and the tidal influence extends 105 km upstream (Woodroffe et al 1989). Sea level rise will very likely further extend the tidal limit and, therefore, cause further adjustment in the channel hydraulics with more frequent overbank flows in some reaches. The response of macro-tidal estuaries to sea-level rise is only partially understood. Previous work generally deals with geomorphological time scales rather than shorter time scales which may of interest, given the projections and time frames for sea-level rise.

In general, perhaps the most significant gap in our current knowledge is the rate at which changes due to overbank flows evolve. It must be recognised, however, that most rivers only overflow for relatively short and infrequent periods, and these may not be long enough for equilibrium to be achieved. Morphological adjustments may depend upon the current state of the bed surface and sub-surface. This will have been built up over a history of flow events. Thus the frequency and magnitude of overbank events set against the adjustment and recovery rate of the river could well be the determining factors in the development of the river morphology.

The pattern of variation of mineral sediment input shows broad correlation with solar variability for the last 1000 years. The youngest peak of mineral sediment input occurs between ~1400 and 1580 AD during the Spörer Solar Minimum; the most intense Minimum in the last 1000 years. (Bard et al 2000). The oldest mineral sediment input Minimum at Winmiyurr Swamp occurred between ~600 and 400 AD, also at a time of low solar irradiance and weak Asian Monsoon (Wang et al 2005).

This tentative analysis suggests that, over the last 2000 years, the competence of streams in the Kakadu area has been controlled by climate variations linked to solar variability. Clark (2006) and others suggest that we are now due for a period of reduced solar irradiance given that solar maxima only last 50–100 years.

11.2.3.3 Changes in vegetation communities

If sea level increases at the projected rate under enhanced climate change scenarios, the distribution and extent of mangrove communities will change (Woodroffe 1990). For mangroves it is not the actual rise in sea level that is important, but the rate of rise (Bayliss et al 2007).

The extent of monsoon forests may increase through elevated $C0_2$ levels and changes to soil moisture relations if wetter wet seasons become the norm. But if a more intensive fire regime eventuates due to hotter dry seasons (extreme event hot spells), then hot fires may result in a contraction of monsoon forest (Bayliss et al 1997).

11.2.4 Management of climate change impacts in Kakadu National Park

The management issues for climate change within the Alligator Rivers Region and Kakadu National Park have been identified through the vulnerability assessment of predicted climate change and sea level rise for the region (Bayliss et al 1997, Eliot et al 1999). The management issues identified, which underpin the following management responses, are summarised as follows:

- *People's perceptions and values in relation to the implications of climate change.* The management response required is to raise awareness of the implications of climate change in Kakadu National Park.
- *Hazard and risk.* Hazard and risk fall into a number of categories:
  - *Natural environment.* The major natural hazards include extreme weather events and coastal processes such as saltwater intrusion. Without a complete understanding of the extent to which freshwater wetlands are at risk, the associated management risk is that vulnerable habitats such as freshwater wetlands may be deemed adequately represented and conserved within Kakadu National Park in the context of climate change impacts. The management response required is to undertake a complete assessment of habitats at risk from climate change impacts and determine whether within the habitats at risk if there is an acceptable proportion of habitat that is protected from climate change impacts within the current reserve design. Bayliss et al (1997) suggest that during past saline inundation, the freshwater floodplain biodiversity was preserved to some degree due to isolated refugia (billabongs and swamps) located in upland reaches of rivers and creeks. However, the effectiveness of these refugia in maintaining the complete suite of pre-existing biodiversity is not known. Conservation of the refugia and particularly their floodplain flora requires a management response that protects them from feral animal and weed disturbances.

    The impacts of climate change on monsoon forests are not clear. The management response for protecting this habitat from a potential increase in 'hot' fires is to continue with current fire management strategies.
  - *Built environment*. There will be increased risk to the built environment under climate change associated with damage to infrastructure such as roads, bridges and buildings. The management response required is the possibility of greater damage to infrastructure needs to be factored into future management plans.
  - *Cultural and heritage*. Cultural and heritage values can be viewed from both a Binninj and Balanda perspective. The risk posed is that if habitats are negatively impacted under climate change then the habitats may lose their original condition that led to their cultural or heritage status.
  - *Environmental health*. Bayliss et al (1997) stated that a predicted 20% increase in summer rainfall will alter wetland inundation parameters such that conditions will favour the breeding of mosquitoes and other insect pests, which has the potential to increase the incidence of infectious diseases in residents and visitors. There is uncertainty around the summer rainfall projections as outlined previously in this paper, and a 20% increase is the upper Figure in the range for projections by 2070 (Hennessy et al 2004). It is unclear how this will alter wetland inundation parameters

but some of the health issues affected by climate change (as listed by Hennessy et al 2004), which may be of relevance to management responses within Kakadu National Park, include: increase in heat stress, increase in flood-related injuries, greater risk for Dengue fever and an increase in diarrhoeal admissions to hospital. Furthermore, lower income populations such as Indigenous communities will be most affected by these health impacts.

- *Governance*. Governance structures in Kakadu National Park and the surrounding regions (Arnhem Land to the east and the wetland complexes to the west) have not been developed to address an issue as complex as climate change. Climate change impacts will not be restricted to governance boundaries and the management response required should develop institutional arrangements that enable integrated management of environments such as the coastal zone.
- *Strategic management*. Strategic management should focus on regional development and natural and cultural resource conservation. The management response required to address regional development issues needs to recognise the competing priorities amongst the various stakeholders for use of resources. Resource conservation is coupled with regional development and needs to be examined within the regional context.
- *Acquisition and custodianship of information*. Information management is a crucial issue as good information management leads to efficiencies in researching and monitoring habitat change and evaluation of management actions. The management response for information management requires that processes for custodianship, access and centralisation of information are developed and adhered to.
- *Environmental research and monitoring*. Ongoing research and monitoring of vulnerable habitats, particularly in the coastal zone, is necessary. This will provide an information base upon which management strategies can be devised. Management actions will be able to be assessed through ongoing monitoring,. Management responses require the assessment of the significance of observed changes within the context of natural variability.

11.2.5 Key knowledge gaps

- Eliot et al (1999, 73) stated that ‘There has been no systematic examination of perception and values with respect to management of the Alligator Rivers Region’. If this is true, a study needs to be initiated that surveys and documents a wide range of stakeholder perception and values in management activities, including management actions for climate change impacts.
- An economic value needs to be determined on the natural resources that are at risk from climate change impacts. Economic valuation has been undertaken for the Mary River and the Daly River. A similar approach may be undertaken for Kakadu National Park.
- There is a lack of knowledge relating to the hydrodynamic processes in the Van Diemen Gulf and their impact on the ARR shoreline (Bayliss et al 1997).
- A Spatial Information System (SIS) that clearly illustrates long-term environmental change due to climate change (environmental pre-history to current day and forward model into the future) at multiple spatio-temporal scales is required. In addition to fulfilling an information management role, the SIS would aid in communicating the complexity of climate change impacts in the region to the various stakeholders and raise awareness of potential changes.

- A study of barrages and their use within Kakadu National Park and surrounding regions focusing on successes and use in mitigation (refer to NT DIPE 2003. *Cost-Benefit Analysis of Mary River Salinity Mitigation*).
- Observed rainfall trends (build up rainfall etc) have not been studied in detail and the global models are not predicting what is occurring.

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12 Ranger Mine – Landscape issues for operators and closure of uranium mines in Kakadu National Park

DR Jones[1]

12.1 Focus summary

Areas of the Park that have been, or have the potential to be, impacted by U mining include Jabiluka, Koongarra, Ranger, and the cluster of small abandoned sites in the South Alligator River Valley. Of these sites, those in the South Alligator Valley are the subject of rehabilitation works to be carried out over the next five years, Jabiluka is in a long term care and maintenance mode, and Koongarra is the subject of ongoing discussions with traditional owners. The Ranger Mine is the only operating mine in the Park. It is a big producer by world standards and currently produces 11% of the world's total production of uranium oxide.

The decommissioned and largely rehabitated Nabarlek site located just outside of the north east corner of KNP provides valuble lessons about revegetation aspects of minesite rehabilitation in the wet-dry tropics.

A comprehensive set of environmental objectives for operations and closure of the Ranger Mine is contained in the statutory Environmental Requirements (ERs) attached to the Ranger Authorisation to Operate. The ERs for operations mandate protection of the receiving environment of KNP as well as protection of human health outside of the lease areas. These protection concepts are expanded in the ERs for rehabilitation to include aspects of radiation protection and sustainable rehabilitation.

In particular the ERs for rehabilitation of the Ranger Project Area state that:

- The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of KNP such that the rehabilitated area could be incorporated into the Park.
- Revegetation should use local native plant species similar in density and abundance to those in adjacent areas of KNP to form a sustainable ecosystem which would require a management regime not significantly different to adjacent areas of the Park

Apart from radiation (specified in the Environmental Requirements) no specific closure criteria (ie numeric measures of performance) have been specified or agreed with stakeholders. Hence there are no quantitative measures to define when the objectives spelt out in the two dot points above have been achieved. This lack of closure criteria is a critical gap in the closure planning process, and the acquisiton of the knowledge required to develop technically defensible closure criteria is driving much of the current research effort.

Closure criteria are the quantitative performance benchmarks against which the long term success and sustainability of rehabilitation will be measured (audited), and signoff given for lease relinquishment. In large measure the criteria define the works that must be implemented

[1] Environmental Research Institute of the Supervising Scientist, GPO Box 461 Darwin NT 0801

to produce a final landform that will be environmentally compatible (physically, chemically, ecologically and socially) with the Ranger Environmental Requirements

Current research is directed towards providing the technical basis for developing closure criteria for landform design specification, surface and groundwater quality, and revegetation. Concurrently research projects are investigating the selection and establishment of key plant species, and the threats that weeds and fire pose to the development of a sustainable vegetation assemblage. An especial challenge in this context is the phrase ‘a management regime not significantly different to adjacent areas of the Park’. This has important implications for the ongoing management regimes for weeds and fire and, in particular, raises the issue of whether specific closure criteria relating to weed density and composition may be required.

The long range predicitions of climate change involving more frequent intense extreme events may need to be specifically considered in the context of the design specifications for the Ranger landform.

12.2 Paper

12.2.1 Introduction

Areas of Kakadu National Park (KNP) that have been, or have the potential to be, impacted by uranium mining include Jabiluka, Koongarra, Ranger, and the cluster of small abandoned sites in the South Alligator River Valley. Of these sites, those in the South Alligator Valley are the subject of rehabilitation works to be carried out over the next five years, Jabiluka is in a long term care and maintenance mode, and Koongarra is the subject of ongoing discussions. Both the Ranger Project Area and the Jabiluka Mineral Lease were granted prior to the declaration of the KNP and, although surrounded by the park, are separate entities from Northern Territory and Commonwealth Government regulatory perspectives.

The Ranger Mine is the only operating mine in the Park (Figure 1). It is currently the world’s second largest single producer of U_3O_8 and produces 11% of the world’s primary supply.

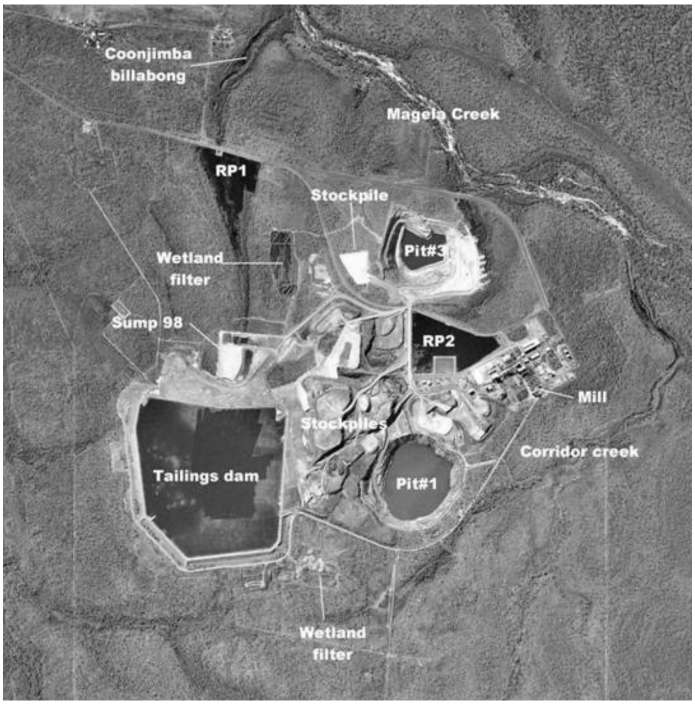

Figure 1 Key Features of Ranger Uranium Mine (2004)

According to the current mine plan, mining of ore reserves in Pit#3 will be completed by the end of 2008, although there are indications that this could be extended to 2011 with highly prospective areas being investigated to the east and south east of Pit#3. Processing of ore is currently proposed to extend to 2020, with decommissioning and rehabilitation of the site extending beyond this date.

12.2.2 Ranger Mine operations

The environmental management of the Ranger site is governed by the Environmental Requirements attached to the Ranger Authorisation (http://www.environment.gov.au/ssd/about/legislation/pubs/ranger-ers.pdf).

These are statutory obligations agreed between the Northern Territory and Commonwealth Governments. During the operation phase the following primary environmental requirements (ERs) apply:

- maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list;
- maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands;
- protect the health of Aboriginals and other members of the regional community; and
- maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region.

The ERs are the high level objectives and are supported in practice by detailed management plans and performance measures.

Twenty five years of water quality and aquatic ecosystem health data collected by the Supervising Scientist Division indicate that there have been no detectable impacts from the Ranger Mine on the downstream aquatic communities (Johnston & Needham 1999, SSD Annual reports 2000–2006). Radiological dose assessments (Martin 2000, SSD Annual reports 2000–2006) carried out using the long monitoring record for airborne (dust and radon) and bushtucker (mussels from Mudginberri Billabong) show that the total radiation exposure to members of the general public attributable to mining (outside of the lease area) is well below the conservative international standard of 1 mSV/y (ICRP, 1991).

A recent comprehensive landscape ecological risk assessment of the Magela Floodplain focusing on protection of its World Heritage environmental values concluded that, under the current operating regime of the Ranger mine, the point source risk from the minesite was orders of magnitude lower than the risk posed by weeds (especially para grass) and feral animals (Table 1).

Table 1 Ranking of landscape (disperse) and minesite (point) risks for Magela Creek floodplain (Bayliss et al 2006)

Category	Pathway	Hazard	Risk rank
LANDSCAPE	Park-wide	Para grass weed	1
	Park-wide	Pig damage	2
	Floodplains	Unmanaged fire	3
		Total ecological risk	0.21
MINESITE	Surface water – Magela Ck	Uranium	4
	Surface water – Magela Ck	Sulfate	5
	Surface water – Magela Ck	Magnesium	6
	Surface water – Magela Ck	Manganese	7
		Total ecological risk	0.00009

12.2.3 Ranger decommissioning and closure

At the end of the mine's life the tailings currently contained in the tailings dam must be returned to the mined out open pits, and the residual void volume in the pits backfilled with waste rock. It is currently proposed by ERA that the final landform will comprise low relief hills such that the view across to Mt Brockman is unimpeded.

There are a number of environmental requirements specific for closure, and these complement the primary environmental objectives listed above.

i. Rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of KNP such that the rehabilitated area could be incorporated into the Park.

ii. Revegetation using local native plant species similar in density and abundance to those in adjacent areas of KNP to form a sustainable ecosystem which would require a management regime not significantly different to adjacent areas of the Park.

iii. Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including traditional owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area.

iv. Tailings must be returned to the mined-out pits, and be contained for a period of 10 000y.

v. Erosion characteristics of rehabilitated area similar to surrounding undisturbed areas.

A secondary environmental objective is that the company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.

Apart from the radiation performance measures defined in ER (iii) above, and the tailings containment period specified in ER (iv), no specific closure criteria (ie numeric measures of performance) have been specified or agreed with stakeholders for post decommissioning performance. The words 'similar' and 'not significantly different' appear several times in the ERs but such descriptions are intrinsically subjective in how they will be interpreted by individuals and by the different stakeholder groups.

Closure criteria are so important because they are the quantitative performance benchmarks against which the long term success and sustainability of rehabilitation will be measured (audited), and signoff given for lease relinquishment. In large measure the criteria will define the works that must be implemented to produce a final landform that will be environmentally compatible (physically, chemically, ecologically and socially) with the Ranger Environmental Requirements.

The current lack of agreed closure criteria is a significant gap in the closure planning process, and the acquisition of the knowledge required to develop technically defensible closure criteria is driving much of the current research effort. SSD, in collaboration with colleagues from other institutions, is undertaking a long term program of research to address the following aspects.

- The effect of proposed physical design parameters (slope angle, slope length, cover type) on erosion stability of the final landform is being assessed using long term geomorphic computer modelling tools (Hancock et al 2006, Lowry et al 2006)
- Factors affecting the emanation of radiation from mine landforms are being investigated at a number of sites across the ARR (Martin 2000, Bollhoefer et al 2006)
- An analogue approach using appropriate nearby areas of KNP for reference is being used to develop a list of key species to be used for rehabilitation. This work involves collaboration between the SSD, Earth Water Life Sciences Pty Ltd and Charles Darwin University, with nursery propagation testing by Kakadu Native Plant Supplies (Bayliss & Bellairs 2006, Gardener et al 2006, Humphrey et al 2006)
- Quantitative analysis of the effects of fire and weeds on Park vegetation to provide the basis for developing appropriate establishment methods, a sustainable management regime, and closure criteria for revegetation of the Ranger landform (Bayliss et al 2007)
- Developing a framework for specifying surface water quality closure criteria for natural waterbodies on site by combining water quality and biological (macroinvertebrate) indicators (Jones et al 2006)
- Participating in a multistakeholder consultation forum with traditional owners to define their expectations for the rehabilitated Ranger site

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13 Fauna – with special reference to threatened species

A Fisher[1] & JCZ Woinarski[1]

13.1 Focus summary

13.1.1 Current knowledge

Broad-scale inventory is good, but some major weaknesses (eg most invertebrate groups, especially in the stone country, and some marine groups).

Notable features of the fauna include: (i) regionally high diversity ('hotspot'); (ii) high rates of endemism (especially in the stone country), including some notably relictual species; (iii) large number of threatened species; (iv) large aggregations of some species groups (including waterfowl congregations of International significance); (v) many species are valuable, as tourist attractions and for use by landholders; (vi) many species disperse widely, including international migrants and species that otherwise move in and out of the Park.

13.1.2 Main threats

- **inappropriate fire regimes:** for many threatened fauna species, the current regime cis characterised by fires that are too frequent, intense or extensive.
- **feral animals:** cats may be causing declines in some native mammals; pigs may be reducing breeding success of marine turtles, and others; cane toads reduce abundance of quolls, goannas, snakes etc; impacts of buffalo, horses, exotic invertebrates, etc. are less clearcut.
- **limitations of knowledge & implementation of knowledge:** there is little information available on trends for most fauna species; and some notable gaps in understanding of management requirements. It is not evident that faunal management requirements (where known) substantially influence management.
- **introduced plants:** introduced pasture grasses affect fauna mostly through influence on fire regimes (but also directly – eg for seed-eating birds); mimosa reduces habitat suitability for wetland species.
- **climate change:** wetland (especially floodplain) fauna may be under risk from sea-level rises; climate change may exacerbate unfavourabality of fire regimes.

13.1.3 How should the Park manage these threats?

- **monitoring**: establish comprehensive and tailored monitoring programs for threatened species (and fauna generally), set up such that they can provide information on efficacy of management options;

1 Biodiversity Conservation Division, Dept. of Natural Resources, Environment and the Arts, Darwin, NT

- **clear and explicit input to management**: enhance the connections between monitoring results, management requirements for threatened species, and explicit management practice and performance reporting;
- **develop cost-effective programs for control of introduced plants and animals**
- **develop reduced targets for fire frequency/extent**

13.1.4 Key knowledge gaps

- Notably little information on trends for most threatened animals (due to lack of specific monitoring programs, or broad-brush monitoring generally).
- Often only meagre information on the factors causing species to decline, or of their responses to management intervention.
- Limited knowledge of marine fauna, and of invertebrate fauna (especially in stone country).
- Limited relevant data-basing
- Limited progression from the rhetoric of 'Through working with Bininj, ecological processes are maintained to ensure the viability of populations of native plants and animals currently occurring in Kakadu'. What does that mean? Is it effective? Is it applied?

13.2 Paper

13.2.1 Management objectives

Stated aims of the 5th Plan of Management are:

> Through working with Bininj, ecological processes are maintained to ensure the viability of populations of native plants and animals currently occurring in Kakadu.

and

> Conserving the distribution, abundance and diversity of native plants and animals and communities is a fundamental objective of Kakadu National Park management.

The Park has a number of obligations under the EPBC Act relating to listed species, listed threatening processes, World Heritage status and Ramsar sites. This may be particularly so for listed threatened species that occur only, or mostly, within Kakadu. The Minister also has obligations for the protection of environmental values under the terms of the leaseback condition. There is also a reasonable expectation that the Park will contribute to the protection of plant and animal species listed as threatened under NT legislation.

Park policy stresses the need for recognition and use of Bininj ecological knowledge; regular monitoring for threatened, significant and indicator species; and improved information to guide management of potential threats.

There are no explicit performance measures, targets, management thresholds, pathways to implementation or other relevant details within the Plan of Management that can usefully be applied to detail necessary actions or to measure the success of performance.

13.2.2 Fauna values

Kakadu National Park (KNP) is clearly of exceptional significance in representing and conserving Australian faunal biodiversity:

- the size and location of the Park ensures it captures a very broad variety of habitats, including eucalypt open forest and woodland, mangrove, floodplain, riverine, monsoon rainforest, stony hills and sandstone plateau, most of which have distinct fauna assemblages, including some species of highly restricted distribution;
- the Park also includes a significant north-south gradient in annual rainfall, which is a major factor structuring fauna distribution.
- native vertebrate fauna of the Park includes 66 mammals, 289 birds, 127 reptiles, 26 frogs and 61 freshwater fish species. This represents c. 70% of all vertebrate species occurring in the NT tropical savannas (~ N of 18°S);
- the number of invertebrate species in KNP is unknown for most groups, but includes at least 309 ant species, 105 caddis-flies, 116 chironomid midges, 58 grasshopper, 50 termites, 90 dragonflies, 24 mayflies and 80 butterfly species, with an estimated complement of more than 10,000 insect species;
- the western Arnhem Land plateau, including a substantial area within Kakadu, is an important centre of endemism. This is best documented for plants, but also includes c. 20 vertebrate species (1 frog, 12 reptiles, 3 birds, 2 mammals), at least 25 spp of macro-crustacean and presumably significant numbers in other invertebrate groups (many invertebrate species are currently known only from the Kakadu region, but the lack of broader inventory makes it difficult to assess the significance of these records);
- 31 fauna species known to occur in KNP are currently listed as threatened under Commonwealth and NT legislation. A further 65 species are listed as migratory species under the EPBC Act;
- extensive wetlands in the Park are listed under the Ramsar Convention and on the national Directory of Important Wetlands. These wetlands support at least 60 waterbird, 35 wader and 59 fish species, with accumulations of up to 2 million waterbirds in the late Dry season.

13.2.3 State of knowledge

Kakadu National Park has long been a focus for faunal biodiversity research in Northern Australia. Compared to most of the tropical savannas, the vertebrate fauna and parts of the invertebrate fauna of Kakadu are exceptionally well known. Faunal research within KNP has included:

- initial surveys of vertebrates and some invertebrates in 1972/73 during the Alligator Rivers Region fact-finding study;
- major inventory surveys of terrestrial vertebrates in the 1980s and early 1990s;
- more targeted surveys of some habitats and/or taxa (such as monsoon rainforest).
- a large number of studies in aquatic ecology and taxonomy by eriss (and its precursors);
- monitoring of distribution and population of waterbirds and crocodiles;
- sampling of a variety of vertebrate and invertebrate taxa during the Kapalga fire experiment;

- monitoring of terrestrial vertebrates in the past decade, both broadly and targeting species of interest (such as quolls and goannas);
- a variety of autecological studies, mostly of threatened or iconic species (such as Leichhardt's grasshopper).

Nevertheless, major components of the fauna (notably invertebrates) remain little or only patchily known (particularly in the stone country) and for very few species are there sufficient data to precisely define their management needs.

13.2.4 Threatened species

Species may be listed under the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 and/or the *Territory Park and Wildlife Conservation Act* 2001. Threatened fauna (and flora) in Kakadu NP were reviewed by Woinarski (2004), although there have been significant revisions to these lists since 2004, and particularly since the previous plan for a threatened species program in KNP (Roeger & Russell-Smith 1995). While there is now some stability in the threatened species list, through the application of explicit IUCN criteria and relatively good data for most vertebrate groups, there are likely to be future additions (or possibly deletions) as further inventory and monitoring is undertaken, particularly of invertebrates

A total of 31 fauna species occurring in KNP are currently listed as threatened (4 fish, 4 marine turtles, 5 terrestrial reptiles, 9 birds, 9 mammals), with 21 spp listed under *EPBCA* and 26 under *TPWCA* (Table 1). A larger number of vertebrate species are listed as 'data-deficient' under the *TPWCA*, while 65 spp (mostly birds) are listed as 'migratory species' for the purpose of the *EPBCA*. Currently, no invertebrate species known to occur in KNP are listed as threatened.

There are national Recovery Plans for some threatened vertebrates that occur in KNP, including the four marine turtles, partridge pigeon/crested shrike-tit/masked owl (multi-species plan) and golden bandicoot / golden-backed tree-rat.

The threatened fauna within KNP is a disparate collection of species, rather than a coherent group responding to one or few specific threats. Some species (notable marine turtles and fish) are threatened across their broader range by an array of factors but are relatively secure and protected from these threats within KNP. The protection of some species within KNP is probably of peripheral significance to their national conservation, while other species have significant populations / extents within KNP and continue to be subject to significant threatening process within the Park. Woinarski (2004) listed 13 fauna species (speartooth shark, flatback turtle, yellow-snouted gecko, oenpelli python, partridge pigeon, white-throated grasswren, yellow chat, gouldian finch, northern brush-tailed phascogale, Arnhem leaf-nosed bat, brush-tailed rabbit-rat, arnhem rock-rat, Arnhem Land egernia) for which KNP is of moderate to high significance to the status of the species (with a further 8 species having 'uncertain' significance).

Recent targeted surveys have sought to clarify the distribution and status of Arnhem Land egernia (2003-04), yellow chat (2003-04) and golden-backed tree-rat (2005-06). The latter project will continue in 2007, but has not yet confirmed the persistence of the species in the Park. Four other threatened species (northern shrike-tit, golden bandicoot, bare-rumped sheathtail-bat, false water-rat) have not been recorded in the Park for at least 25 years, and all are known from only one or two reports. It is probable that the golden bandicoot and golden-backed tree-rat have become extinct in the Park area, since around the time of the Park's declaration.

Appendix B (attached) also provides a summary table of listed threatened plant species that occur in (or nearby to) KNP.

13.2.5 Threatened ecological communities

No areas within KNP are currently listed as 'threatened ecological communities' under the *EPBCA*, although there is a current nomination for sandstone heathlands of the Arnhem plateau.

13.2.6 Declining species

There is accumulating evidence of an ongoing decline in some mammal species across broad landscapes in northern Australia. Disturbingly, much of this evidence has been collected within KNP:

- capture rates during intensive sampling for small mammals at Kapalga fell from as high as 28% in 1986–87 to as low as 4% during 1989-93 and 2.4% in 1999. Declines, however, were not consistent throughout the mammal fauna – 7 species (larger rodents and dasyurids, possum, bandicoot) had significant declines while 4 (smallest dasyurid, smaller rodents) had significant increases. Additional sampling in 2003 of a small set of sites previously studied in 1979–83 confirmed a substantial decline in black-footed tree-rat, northern brushtail possum and fawn antechinus;
- resampling during 2001 of 263 fauna survey sites in Stage III from baseline surveys during 1988-90 showed significant decline in 5 of the 18 most frequent mammal species (while a further 6 species infrequently recorded in the first survey were absent in 2001). Declines appeared to be more pronounced in rocky areas and lowland woodlands than mesic habitats;
- resampling in 2002 of a landmark survey of sandstone fauna at Nawurlandja during 1977-1980 showed substantial decline in capture rates of 3 species (quoll, sandstone antechinus, Arnhem rock-rat), whereas the numbers of the smallest and least specialised species (common rock-rat) increased;
- by contrast, resampling in 2002 of the smaller number of baseline survey sites in Stages I and II established in 1980-83 showed little evidence of change in the mammal fauna, while resampling sites at Jabiluka in 2003(previously sampled in 1979-81) showed a general increase in capture rates (except for possum, sandstone antechinus and Arnhem rock-rat);
- a cogent example of decline is the brush-tailed rabbit-rat. Descriptions by early naturalists (Dahl, Collett, Tunney) suggest this species was widespread and abundant in the Alligator Rivers region and Arnhem Land around 1900. In the early 1970s, it was described as reasonably common in the lowland open forests and woodlands of the Kakadu area. Systematic sampling of wildlife in Stages I and II in 1980–83 found it in 3 of 30 sites, and it was described as 'uncommon'. Subsequent sampling throughout KNP from late 1990s to present has located it in 1 of over 300 sites. This species is now classified as Vulnerable (TPWCA) and extinction within KNP is probable: in contrast, declines are less marked at some other locations (notably on Cobourg Peninsula). The causes of decline are likely to be either (or both) unfavourable fire regimes or cats. Evidence from elsewhere suggests it is strongly associated with a fire regime of infrequent and/or highly patchy burns (which may be important to retain suitable habitat of fallen logs and perennial grasses) [see Appendix case study]. In part because of this substantial decline

within Kakadu, this species is now being nominated to be listed as threatened under the EPBC Act: it has already been listed as threatened under Northern Territory legislation.

That research on mammal declines has concentrated in KNP reflects the relative abundance of historical information and emphasises the value for monitoring of the large array of sites at which there is baseline fauna data, that has been collected in a systematic and repeatable fashion. Unfortunately it also emphasises that the mammal fauna of the park has not been successfully insulated from negative impacts during the period that the area has been actively managed for conservation, and that a series of extinctions may yet occur within this premiere reserve. It is also important to illustrate the point that presumptions of probable status based on information from 20-30 years ago may be misleading, and that continued monitoring is essential.

Historical and likely ongoing declines in northern Australia have also been noted for granivorous birds (including some parrots, pigeons, finches and button-quail), which has been attributed to reduced habitat quality due to the effects of changed fire regimes and pastoralism. Declining species occurring in KNP include common bronzewing, partridge pigeon, star finch, gouldian finch, chestnut-breasted mannikin and chestnut-backed button-quail. A detailed study of partridge pigeon in KNP suggested habitat suitability was influenced by seed availability and a structurally patchy understorey associated with fine-scale burning patterns, and there has been an attempt to test this in a management experiment involving Park staff and Bininj (Fraser et al 2003).

13.2.7 Threatening processes

Significant threatening processes relevant to terrestrial fauna within KNP include:

13.2.7.1 Changed fire regimes

Changes in fire regimes following the disruption of traditional Aboriginal land management, particularly an increase in frequency and/or a decrease in the spatial or temporal heterogeneity of burning is presumed to be a factor in the decline of many fauna species. In almost all cases, the current regime can be characterised as having too many fires of too high an intensity and extent to be suitable for the declining species.

13.2.7.2 Predation by feral predators

Predation by feral cats (and possibly dogs) is likely to have contributed to the decline of a number of mammal and ground-dwelling bird species, although there are few data to assess the severity of the impact. Management of cats at broad landscape scales is very difficult, although control mechanisms are under development. Feral pigs and dogs may have severe impacts in nesting success of turtles, including threatened marine species.

13.2.7.3 Predation and/or poisoning by cane toads

Cane toads reached Kakadu NP in 2001 and have subsequently spread throughout the Park. Sampling of 110 sites in the Mary River District in the year before and after cane-toad invasion showed a dramatic decline in northern quoll. Short-term impacts on other vertebrates were less obvious or absent. Subsequently, detailed monitoring of the quoll population in the East Alligator region demonstrated that toads were responsible for their local drastic decline (Oakwood 2004), but there may be limited locations in which some quolls have persisted.

Many other species occurring in KNP are potentially susceptible to impacts from cane toads [van Dam et al (2002) listed 11 definitely, 16 probably and 124 possibly susceptible] although there is very limited evidence of the severity, and persistence over time, for many of these.

Monitoring of goanna populations in the park (using reports from staff and tour groups) during 2004–2006 showed that while larger species (*Varanus panoptes, gouldii, mertensi*) have declined, they all still persist, particularly in some strongholds such as South Alligator floodplain.

13.2.7.4 Grazing by feral stock

Grazing by introduced livestock (both controlled and feral) has been implicated in the decline of bird and mammal species across northern Australia, where very little of the landscape is free of such impacts. Although there are some control programs for some feral species, horses, cattle and buffalo remain in many areas of Kakadu, reducing its value as a refuge from these impacts.

13.2.7.5 Habitat alteration by weeds

The greatest potential for impact by introduced plants is in the floodplains (mimosa, para grass) and lowlands (gamba and mission grass). The impacts of the spread of exotic pasture grasses may be compounded by the greater fuel loads supporting increasingly intense fires.

13.2.7.6 Climate change

Although it remains difficult to predict precise impacts, the effects of climate change are likely to be most evident in changes to the hydrology of wetlands (including saltwater intrusion) and fire regimes. Reduction in the extent and/or quality of freshwater wetlands may have some substantial impacts on the ability of these systems to support a rich and diverse waterfowl fauna, one of the key attributes of KNP's Ramsar and World Heritage listing.

13.2.7.7 Visitor pressures

Visitor pressures include recreational fishing (which may contribute to mortality rates for some threatened species) and localised impacts on popular sites such as waterholes. The latter may be significant for some endemic species such as macro-crustaceans that may be restricted to one or few individual pools.

13.2.7.8 Responses to threats

There is only poor information on the relative importance of these threats to many threatened or declining fauna species, and little or no quantitative data on the response of species to management of these threats. Some threats, such the recent spread of cane toads throughout KNP, may be indubitably severe but are not amenable to management action within the Park at present.

Woinarski (2004) made 10 recommendations for threatened species management in KNP. Key recommendations included:

- further survey effort to better define the status of poorly known species (including those which may be locally extinct) and for selected invertebrate groups;
- establishment and/or maintenance of monitoring programs (both for individual species and broad-scale fauna monitoring);
- continued management of threatening processes, coupled to targeted research on the response of threatened species to these threats and management actions; and
- improved systems for storing, communicating and reporting information about threatened species.

13.2.8 Monitoring

Fauna monitoring programs within KNP are currently largely restricted to those for marine turtles, crocodiles and waterbirds, and monitoring of aquatic environments associated with the Ranger mine.

Most of the current knowledge of threatened fauna, and changes in fauna status, within KNP has come from what could be characterised as ‘research’ rather than ‘monitoring’ programs (although in some cases this has involved repeat sampling of sites). However, the framework for an ongoing broad-scale fauna monitoring program has been created with the establishment of a network of 134 sites for the Kakadu Fire Monitoring Program, which sample most environments in each district. Vertebrate fauna has been sampled using standardised methods in almost all of these plots, and resampled (on a 5-year rotation basis) in a few. However, the fauna monitoring component of this Fire Monitoring Program has lapsed, and there is currently no explicit commitment to restore or continue it.

It is important to recognise that this broad-brush approach needs to be complemented by specifically targeted monitoring of individual significant species, which are unlikely to be well represented in the general fauna monitoring sites. Although there have been targeted surveys of a number of threatened species occurring in the park, and sufficient information on other species to form the baseline for ongoing monitoring, there is currently few formal species-level monitoring programs (Table 1): for most (>80%) threatened species, there are no programs occurring that measure trends in abundance, nor responses of these species to designated management actions for them. In almost all cases, there is no system in place that will allow managers to report that populations of these threatened species have increased or decreased over the course of this, or any previous, Plan of Management.

Most fauna research and monitoring activities in KNP have been carried out by external agencies or consultants, and there has been mixed success in involving Park staff and Bininj in these activities. Information about the Park’s fauna and data from survey and monitoring programs is also widely scattered, sometimes in reports that are difficult to access (although most data for vertebrate fauna is compiled in NRETA databases). The development of a consolidated information management system for KNP, which both makes existing information generally accessible, and provides a mechanism for storage and dissemination of ‘new’ data and information, will be an important component of effective biodiversity monitoring.

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13.2.9 References and further reading

A good review and bibliography for Kakadu fauna is found in Press et al (1995) and for wetland and aquatic biodiversity in Finlayson et al (2006). Only a subset of their lists is given here, representing the breadth and scope of research, and some recent publications are added. A large body of information is held in unpublished reports, principally those prepared by ***eriss*** and/or for Parks Australia North.

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Table 1 Summary list of threatened fauna species recorded from Kakadu NP, indicating legislative status (Commonwelath and NT), significance of Kakadu, major threats, existence of any monitoring program and habitat. Abbreviations: CE=Critically Endangered; EN=Endangered; VU=Vulnerable. For Northern Territory status only: NT=Near Threatened, LC=Least Concern and DD=Data Deficient. Significance: H=high, M=medium, L=low. Habitat: M=marine, E=estuarine, R=riverine, C=coastal, F=freshwater, LW=lowland woodland, SS=sandstone. Updated from Woinarski (2004) to include recent revisions to the TPWCA

Scientific name	Common Name	EPBCA	TPWCA	Kakadu significance	major threats	existing monitoring	habitat
Glyphis sp. A	Speartooth Shark	CE	VU	?H	?fishing	nil	E, R
Glyphis sp. C	Northern River Shark	EN	EN	?H	?fishing	nil	E, R
Pristis clavata	Dwarf Sawfish	-	VU	M	?fishing	nil	M, E, R
Pristis microdon	Freshwater Sawfish	VU	VU	?H	?fishing	nil	E, R
Caretta caretta	Loggerhead Turtle	EN	EN	L	?fishing; harvesting;	nil	M, C
Chelonia mydas	Green Turtle	VU	LC	M	?fishing, harvesting	nil	M, C
Lepidochelys olivacea	Olive Ridley	EN	DD	L	?fishing, harvesting	limited	M, C
Natator depressus	Flatback Turtle	VU	DD	M	?fishing, harvesting; nest predation (pigs, dogs, goannas)	regular, at breeding sites	M, C
Varanus mertensi	Merten's Water Monitor	-	VU	L-M	cane toad	some	F, R
Varunus panoptes	Floodplain Goanna	-	VU	L-M	cane toad	some	F, LW
Diplodactylus occultus	Yellow-snouted Gecko	EN	VU	H	fire; exotic grasses	proposed survey	LW
Egernia obiri	Arnhemland Egernia	EN	EN	H	?cats; fire	nil (some baseline information)	SS
Morelia oenpelliensis	Oenpelli Python	-	VU	H	?poaching	nil	SS
Dromaius novaehollandiae	Emu	-	VU	L	fire	nil	LW
Erythrotriorchis radiatus	Red Goshawk	VU	VU	L-M	?fire	nil	LW
Ardeotis australis	Australian Bustard	-	VU	L	?fire; hunting	nil	LW, F
Geophaps smithii smithii	Partridge Pigeon	VU	VU	H	fire; cats/dogs/pigs	some irregular counts	LW
Tyto novaehollandiae kimberli	Masked Owl	VU	VU	L	?fire	nil	LW

Scientific name	Common Name	EPBCA	TPWCA	Kakadu significance	major threats	existing monitoring	habitat
Amytornis woodwardi	White-throated Grasswren	-	VU	H	fire	nil (some baseline information)	SS
Epthianura crocea tunneyi	Yellow Chat	VU	EN	H	fire; exotic grasses; feral stock	nil (some baseline information)	F
Falcunculus whitei	Northern Shrike-tit	VU	VU	L	?fire	nil	LW
Erythrura gouldiae	Gouldian Finch	EN	EN	M	fire; exotic grasses; feral stock	nil	LW
Dasyurus hallucatus	Northern Quoll	EN	CE	?	cane toad; fire	decline monitored	LW, SS
Phascogale pirata	Northern Brush-tailed Phascogale	-	VU	H	?fire	nil	LW
Isoodon auratus auratus	Golden Bandicoot	VU	EN	?	?fire; cats	nil	?SS
Saccolaimus saccolaimus nudicluniatus	Bare-rumped Sheathtail Bat	CE	DD	?	?fire	nil	LW
Hipposideros inornata	Arnhem Leafnosed Bat	-	VU	H	?	nil	SS
Conilurus penicillatus	Brush-tailed Rabbit-rat	-	VU	M	?fire; cats; grazing; exotic grasses	nil (some baseline information)	LW
Mesembriomys macrurus	Golden-backed Tree-rat	VU	CE	?	?fire; cats; grazing; exotic grasses	no monitoring, but 2 recent targeted surveys	?SS
Xeromys myoides	Water mouse (False water-rat)	VU	DD	?	?fire; grazing; exotic grasses; cats	nil	C, F
Zyzomys maini	Arnhem Rock-rat	VU	VU	H	fire	no formal monitoring, but some baseline and re-sample	SS

Appendix A. Case study of decline of one threatened fauna species: the brush-tailed rabbit-rat

The native rodent *Conilurus penicillatus* is now known from a small range of sites in the Top End of the Northern Territory, one island in Queensland, a very restricted area in the north Kimberley, and two sites in New Guinea. The Top End of the Northern Territory is recognised as its stronghold. However, it is now recognised as Vulnerable under NT legislation.

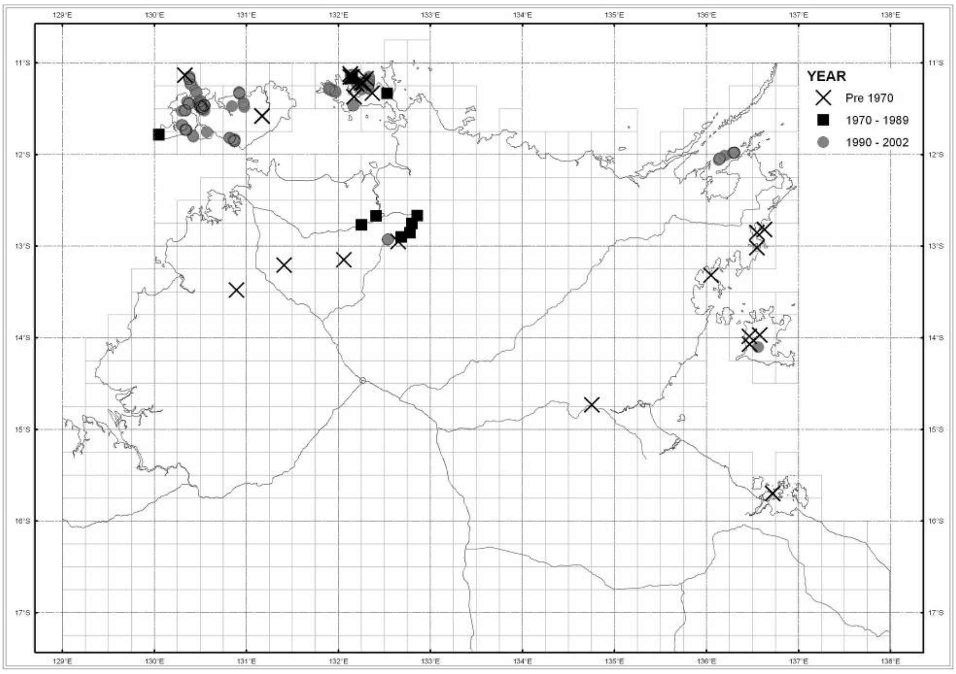

Figure A1 Known NT records of *Conilurus penicillatus*

Historical

There is limited information on its historical status. The most substantial information is from collectors operating in the last decade of the nineteenth century and first decade of the twentieth century. These noted:

> in Arnhem Land is everywhere common in the vicinity of water (Dahl 1897)

> Numerous all over Arnhem Land, and in great numbers on the rivers on the lowlands (Collett 1897)

As further corroboration of its status in the area at this time, Tunney collected 40 specimens in the Alligator Rivers region between 1902 and 1903.

1960s

Apart from some incidental records by Donald Thomson in Arnhem Land in the 1940s, there were no subsequent assessments of its status (or that of most other Top End native mammals) until the 1960s, when CSIRO began survey and collecting for the Alligator Rivers Region fact-finding study. Describing results from that time, Calaby (nd = *ca* 1971) stated that, in the Kakadu area, it was:

> a reasonably common species, found chiefly in woodland with suitable hollow tree shelters

and they collected a substantial sample from a range of sites (near Patonga, Nourlangie Camp, etc.) in Kakadu.

Early 1980s

Subsequently, a more systematic and quantitative fauna survey (the CSIRO survey of stages 1 and 2 of Kakadu National Park: Braithwaite 1985) sampled mammals at 30 sites [of which 18 were eucalypt forest and woodlands] six times over a three-year period (1980-83). *Conilurus* was found at 3 of these sites (ie 17% of the eucalypt forest/woodland sites), with a total trap success of 0.0386% [=5 individuals captured in 12,960 trap-nights].

Summarising results of this survey, Braithwaite (1985) stated that, in Kakadu:

> This beautiful uncommon species is likely to be widespread in open forest and woodland.

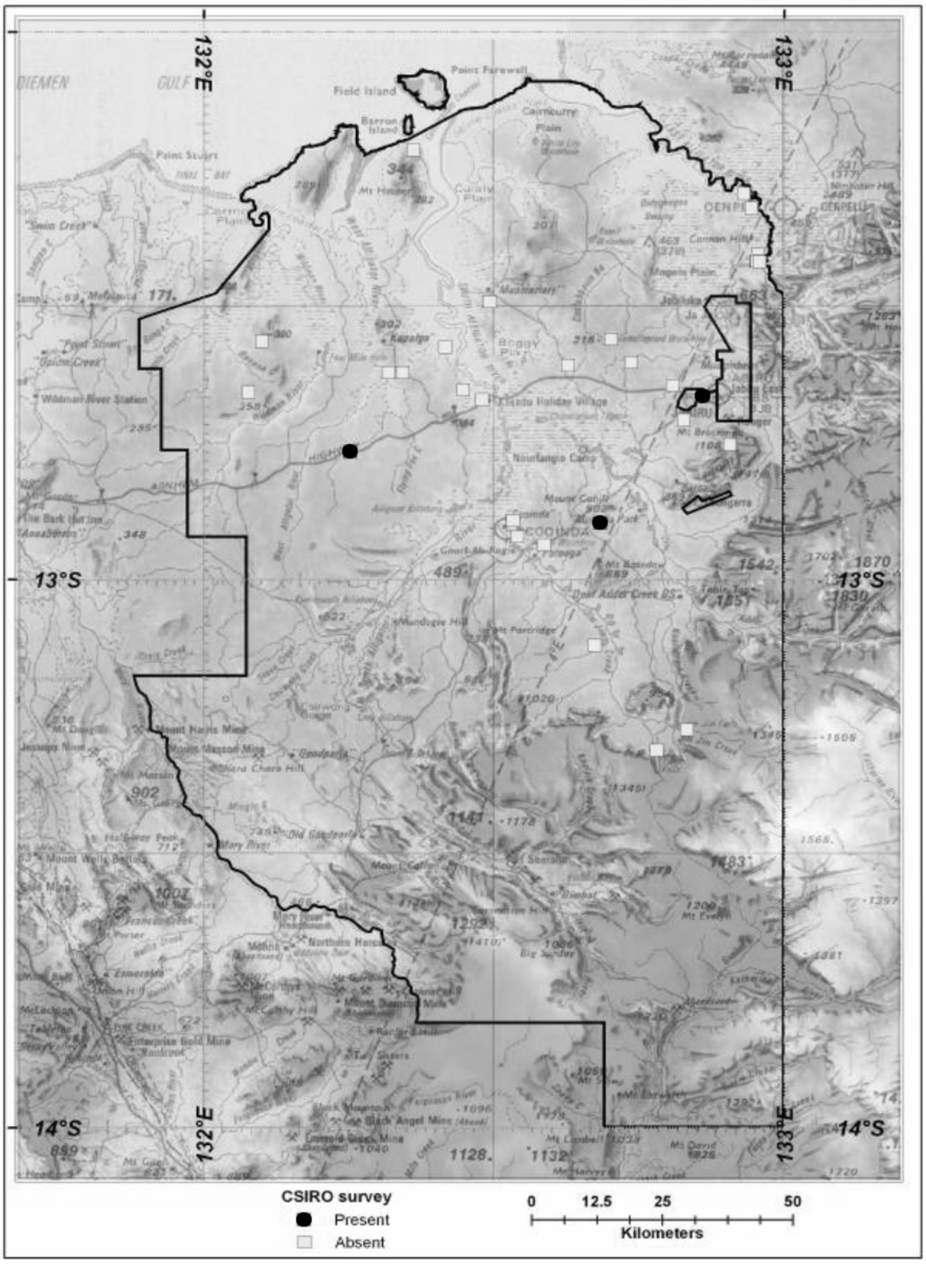

Figure 2 Occurrence of Conilurus at CSIRO Stage 1 & 2 survey sites (1980-83): dark circle=present; pale square=absent

Late 1980s – now

Subsequent to the Kakadu Stages 1 and 2 surveys, CSIRO sampled a large series of sites in Stage 3 of Kakadu. This included 380 sites (quadrats) sampled between 1988 and 1990 (total effort of 30,400 trap-nights) (Woinarski and Braithwaite 1990, 1991). No *Conilurus* was caught. 263 of these sites were re-sampled in 2002, and again no *Conilurus* were caught (Woinarski et al 2002).

Survey more broadly across the Park as part of the fire monitoring plot program included mammal survey at 114 fire monitoring plots (totaling 8,208 trap-nights effort), from 2001-04. No *Conilurus* was caught (Watson and Woinarski 2003, 2004).

In 2002, Watson and Woinarski (2003) re-sampled 16 of the 30 CSIRO Stages 1&2 sites, including sampling 14 of the original 18 eucalypt forest and woodland sites (for a total of 3456 trap-nights), including all three sites where *Conilurus* were recorded in 1980–83 (albeit the 2002 sampling was for one session only rather than the six sessions used in 1980–83). No *Conilurus* was caught. The only site where *Conilurus* is known to persist in Kakadu is at Mardugal campground, where Firth undertook a series of studies from 2002 to 2005 (Firth et al 2005, 2006a).

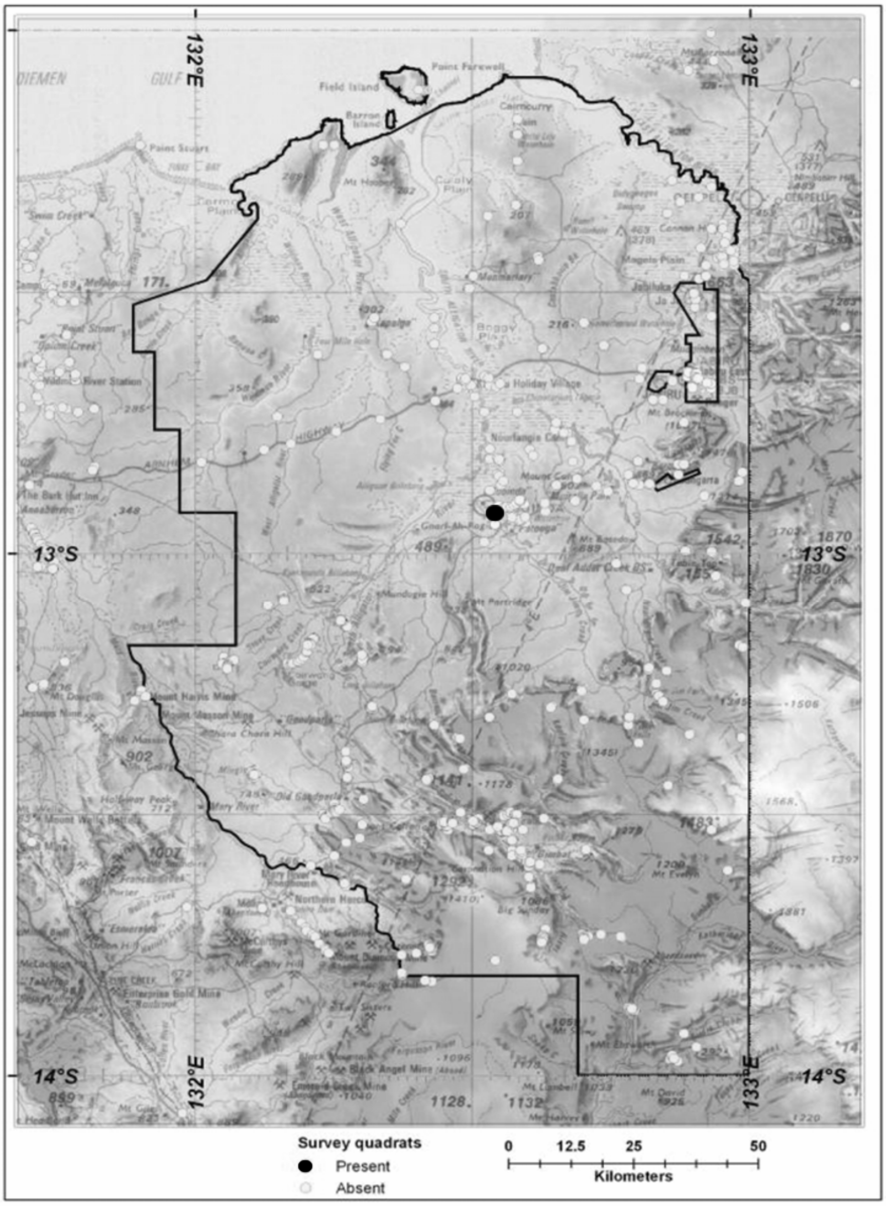

Figure 3 Occurrence of *Conilurus* at survey sites sampled since 1988: large, dark circle=present; smaller pale circles=absent

Conclusions

Over the space of little more than 100 years, *Conilurus* has gone from a status of common' and 'numerous' to almost extinct in the Kakadu area. This change appears to have happened mostly since the late 1960s, when it was still regarded as 'reasonably common'. Some decline appeared to have occurred between the late 1960s and 1981–83, and the decline appears to have continued since 1983. On these trends, it is highly likely that the species will become extinct in Kakadu in the next 10–20 years.

The most likely cause of decline is inappropriate fire regimes. The diet of *Conilurus* mostly comprises seeds, particularly of perennial grass species (Firth et al 2005). The species shelters during the day mostly in hollow logs. The seed resource and log availability are both likely to be diminished by frequent, intense and/or extensive fires; and elsewhere (on the Tiwi Islands), Firth et al (2006b) found that the occurrence of *Conilurus* was very strongly and positively associated with time since fire.

Appendix B. Summary list of threatened plant species recorded from (and nearby) Kakadu NP, indicating legislative status (Commonwelath and NT), significance of Kakadu, major threats, existence of any monitoring program and habitat.

Abbreviations: CR=Critically Endangered; EN=Endangered; VU=Vulnerable. For Northern Territory status only: NT=Near Threatened, LC=Least Concern and DD=Data Deficient. Significance: H=high, M=medium, L=low. Habitat: M=marine, E=estuarine, R=riverine, C=coastal, F=freshwater, LW=lowland woodland, RF=rainforest, SS=sandstone. Updated from Woinarski (2004) to include recent revisions to the TPWCA.

Scientific name	Common Name	EPBCA	TPWCA	Kakadu significance	Major threats	Existing monitoring	Habitat
Acacia sp. Graveside Gorge		CR	CR	H	fire	some	SS
Cycas armstrongii			VU		fire, weeds		LW
Freycinettia excelsa		-	VU		?pigs, fire, weeds		RF
Hibiscus brennanii			VU	H	fire		SS
Lithomyrtus linariifolia			VU	M	fire		SS
Malaxis latifolia			VU	H	pigs		RF
Monocharis hastata		-	VU	M	buffalo, pigs, climate change, weeds		
Sauropus filicinus		VU	DD	H	fire		SS
Utricularia dunstaniae			VU	M			F, LW
Species occurring nearby (mostly on Arnhem Land plateau)							
Boronia quadrilata	-		VU				SS
Boronia viridiflora			VU				SS
Cephalomanes obscurum	VU	-	EN			F	SS
Ectrosia blakei	-		DD				LW
Eleocharis retroflexa	-		DD				SS
Toechima sp. East Alligator		EN	EN		?fire		SS
Utricularia singeriana			VU				SS, F

-

VU

VU

VU

14 Marine/mangroves – looking after coastal country and culture in Kakadu National Park

I Kiessling[1], R Kennett[2], R Bartolo[3], H Larson[4], N Smit & S Whiting[5]

14.1 Focus summary

14.1.1 Current knowledge in relation to those KNP's management objectives

- Despite the importance of the marine environments of the Van Diemen Gulf and the Kakadu coast as critical nursery and breeding habitats for a number of commercially, culturally and conservation significant species, they remain relatively poorly studied;
- Information that is available tends to be focused on species of commercial significance, though more recent fish and seagrass surveys have started to document species and habitats of the region more broadly;
- Information on the substantial cultural heritage values associated with the coastal and marine environments in and adjacent to Kakadu National Park are held by Traditional Owners and other Park managers.

14.1.2 Key threats to landscape health in KNP

- Little opportunity for Bininj to guide the management of marine activities that have the potential to impinge on the cultural values of coastal and marine areas;
- Lack of scientific data on marine habitats and species adjacent to Kakadu;
- Unknown levels of use within marine and coastal environments within and adjacent to Kakadu;
- The impact of commercial fishing operations on marine habitats and species (both target species and bycatch) within and adjacent to Kakadu;
- The impact of high and/or unregulated numbers of recreational fishers on marine and coastal habitats and species within and adjacent to Kakadu.

14.1.3 Proposed management options for maintaining and/or restoring a resilient and healthy landscape in KNP

- Collaborative research efforts between Bininj with advice and assistance where necessary from other Park managers and scientists as a foundation to broader conservation and management of marine and coastal environments in the Kakadu region;

[1] School for Environmental Research, Charles Darwin University, Darwin 0909
[2] North Australian Indigenous Land and Sea Management Alliance, Charles Darwin University, Darwin 0909
[3] Environmental Research Institute of the Supervising Scientist, GPO Box 461 Darwin NT 0801
[4] Museum and Art Gallery of the Northern Territory, PO Box 4646, Darwin, NT 0801
[5] Northern Territory Department of Natural Resources, Environment and the Arts

- Close cooperation between Parks managers and the Northern Territory Government in the conservation, management and regulation of activities impinging on the natural and cultural values of the Van Diemen Gulf adjacent to Kakadu National Park;
- Introduction of conservation and management strategies beyond the Park's coastal boundary that acknowledge the high connectivity between the catchments of Kakadu National Park and adjacent coastal and marine environments.

14.1.4 Key knowledge gaps

- Consultation with Bininj and other managers regarding marine conservation priorities;
- Mapping of key marine habitats and species with particular reference to species of cultural, conservation and/or economic significance;
- Collation of information regarding levels of use of and visitation to marine and coastal environments, infringements and impacts arising from human activities;
- Development of a quantitative data collection methodology to determine levels of use and visitation to marine and coastal areas, measures of recreational effort and take and the degree of impact on species, populations and habitats arising from these activities;
- Detailed bathymetric and substrate mapping of the Van Diemen Gulf as a basis for better understanding coastal processes, benthic habitats, and maintenance of human safety.

14.2 Paper

14.2.1 The coastal country of Kakadu

Kakadu National Park covers almost the entire catchment of the South Alligator River. Kakadu's northern boundary follows the low tide mark of a 120 km stretch of coastline that separates the Park from the shallow waters of the Van Diemen Gulf. Gardangal (Field Island) and Djidbordu (Barron Island) lie at the mouth of the South Alligator River and are part of Kakadu National Park (to their low tide mark). While Kakadu is managed jointly by Traditional Owners and the Director of National Parks under the guidance of the Kakadu Board of Management, the waters of the Van Diemen Gulf abutting Kakadu's northern boundary are under the jurisdiction of the Northern Territory Government.

Traditional Owners of sea country adjacent to Kakadu (Bininj) maintain their relationship to land and sea environments not as separate entities, but as a continuum. The influence of marine systems within Kakadu's boundaries can extend many kilometres inland while correspondingly the influence of freshwater systems may extend many kilometres out to sea. Some of the most ecologically interesting and significant features of Kakadu National Park are the highly dynamic systems at the interface between saline and freshwater systems. However as Kakadu's northern boundary lies at the low tide mark, marine and coastal values have not tended to be well represented within Park boundaries or featured prominently in formal management priorities for the Park. While almost the entire South Alligator River catchment is currently protected and managed within the boundaries of Kakadu, the offshore coastal environments with which the catchment closely interacts are not.

There are few areas in the Northern Territory (or Australia) where there is the potential to consistently manage interactions between terrestrial and marine systems and the human activities within them on such a large scale. The high degree of linkage between marine and terrestrial environments in Kakadu, and the potential for detrimental environmental impacts on natural and cultural values arising from human activities offshore, presents an opportunity for the introduction of comprehensive catchment to ocean conservation and management strategies that extend beyond the Park's current coastal boundary.

14.2.2 Cultural values of coastal country

Coastal and marine areas are very significant to Bininj and there are numerous sites of cultural significance that lie within and adjacent to Kakadu. These substantial cultural heritage values include ongoing associations with sea country, Bininj oral histories, creation stories and significant marine and coastal places.

Long before the arrival of Europeans, Aboriginal groups in the Kakadu area were familiar with Macassan visitors who sailed from the Celebes Islands (Sulawesi). Extensive cultural exchange occurred between these two groups and during each wet season, considerable trade took place (Morris 1996). Much of this historical contact was recorded in the rock art records of Arnhem Land and many Kakadu languages demonstrate features of Indonesian languages (Morris 1996).

One of the first dedicated initiatives to record oral culture in the coastal areas of the Kakadu region was done in 1994 around the East Alligator area (Handelsmann et al 1994). An internal study of traditional knowledge and use of coastal areas by Bininj in Kakadu more generally was undertaken by Parks Australia in 1995 (Blyth 1995). The Northern Land Council has carried out research in relation to cultural heritage associations in the Van Diemen Gulf involving collection of oral histories in collaboration with a number of senior Traditional Owners, and has prepared a confidential and privileged draft consultant report. This research indicates that there are substantial cultural heritage values particularly associated with the eastern portion of the Van Diemen Gulf.

Bininj continue to hunt and gather a wide range of coastal and marine plant and animal species such as marine turtles, fish, shellfish, barramundi, stingrays, and mudcrabs in and adjacent to Kakadu National Park. The previous Kakadu Plan of Management highlights the importance of areas within Kakadu where Aboriginal people can use resources traditionally without having to be concerned about conflict with other Park users (Kakadu Board of Management and Parks Australia 1998). Notwithstanding, Bininj currently have few options for guiding the management of marine activities that have the potential to impinge on the cultural values of coastal and marine areas.

14.2.3 Natural values of coastal country

Kakadu's northern boundary is a stretch of coastline spanning the Wildman, West, South and East Alligator Rivers. The Park lies adjacent to the Van Diemen Gulf, a shallow, semi-enclosed Gulf that is dotted with islands, reefs and shoals. Tidal ranges in the Gulf can vary from 1.0m during neap tides to 7.0m during spring tides. West Alligator Head is the only coastal section of the Park that readily accessible by road and that has facilities provided for public access and use.

Kakadu's coastal environments and the adjacent Van Diemen Gulf comprise a diverse range of habitats including sandy beaches, rocky headlands, mud, shell and gravel substrates, well developed mangrove forests, extensive mud and muddy sand flats, seagrass beds and coral and sponge gardens on rocky reefs (Larson 1997, 2002, Russell and Smit in prep). Collectively, these habitats support a high diversity of vertebrate and invertebrate species, a number of which are listed under the *Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act)* and international conservation agreements.

The Van Diemen Gulf is generally very sheltered except during the wet season when north-west monsoon winds are dominant. The Van Diemen Gulf is unusual in that it is one of the few areas of the Northern Territory's coastal waters where marine bio-physical processes are directly influenced by river systems (DEW in prep.). The number of large rivers entering the relatively closed waters of the Gulf coupled with extensive sheltered shallow water habitats and mangrove forests make it a significant nursery area for a large range of commercial and non-commercial species (DEW in prep). Despite the importance of the marine environments of the Van Diemen Gulf and the Kakadu coast as critical nursery and breeding habitats, they remain relatively poorly studied. Information that is available on marine habitats and species in the Kakadu region is summarised below.

14.2.3.1 Sharks and sawfish

Recent additions to documented Kakadu fauna include sharks and sawfish such as the speartooth shark (*Glyphis* sp A), northern river shark (*Glyphis* sp *C*), freshwater sawfish (*Pristis microdon*), and the dwarf sawfish (*Pristis clavata*). Despite reasonably comprehensive surveys across northern Australia, the river sharks *Glyphis* are only known from relatively shallow freshwater to brackish reaches of the Adelaide and Alligator Rivers systems in the Northern Territory (Larson 2002). Kakadu is also likely to provide important to critical habitat to speartooth sharks, freshwater sawfish and the freshwater whipray (Larson 2002, Pogonoski 2002, Pogonoski et al 2002). Northern Australia's marine environment and Kakadu in particular, are believed to support some of the last remaining viable sawfish populations in the world (Larson 2002).

Sawfish tend to have a higher rate of entanglement in fishing nets than other sharks due to their long sword and lateral teeth (Rose & McLoughlin 2001). Also, despite regulations aimed at prohibiting the practice, sawfish are at particular risk from illegal shark finning in northern Australian fisheries due to their extremely high fin value and susceptibility to capture by multiple gear types. As speartooth sharks and sawfish both appear to have very specific estuarine habitat requirements, they are very vulnerable to netting and poaching, and are believed to be declining throughout most of their range (Pogonoski 2002). Indeed, sawfish are internationally recognised as among the most endangered of all elasmobranch (shark) species, and there are documented cases elsewhere in the world of sawfish being entirely absent from regions in which they were previously common (Pogonoski et al 2002). The fate of sawfish species in Australia is likely to rely on some form of protection in areas where they still occur (Pogonoski 2002, Pogonoski et al 2002).

14.2.3.2 Marine turtles

Gardangal lies within one of the major breeding regions for the Australian endemic flatback turtle (Bayliss et al 1997, Schauble 2002, 2006, Schuable et al 2006). Gardangal and all waters within a 20km radius of it have been identified in the Australian Government Recovery Plan for Marine Turtles as 'habitat critical to the survival' of flatback turtles and a key marine turtle-monitoring site within a national monitoring framework' (Environment Australia 2003). The reef flats and sea grass beds surrounding Gardangal support a substantial feeding population of green turtles (Kakadu unpub. data), and turtles from this population migrate to nesting beaches in Western Australia, Gulf of Carpentaria, the Great Barrier Reef in Queensland, as well as Malaysia (Dethmers et al 2007, Limpus 2007). Hawksbill, loggerhead and olive ridley turtles have also been recorded on beaches and in coastal and estuarine waters in Kakadu (Guinea 1990, Vanderlely 1995).

Targeted nesting surveys of flatback turtles in Kakadu conducted since 1990 show no evidence of a decline in the nesting population, however inconsistency in data collection techniques and variability in data quality limit the strength of this conclusion (Schauble 2002, 2006, Schuable et al 2006). Recent improvements to survey design and practice following a program review should address some of these issues. Nesting populations of marine turtles were also the focus of a Masters thesis project conducted (Vanderlely 1995), and observations of marine turtle numbers and behaviour have been recorded at West Alligator Head by long-term residents Nicky and John Grice (Grice pers com 2002).

14.2.3.3 Saltwater crocodiles

Saltwater crocodile populations in estuarine environments were first surveyed in the Park in the late 1970s (Messell et al 1979). Since then, both external researchers and Park staff have undertaken monitoring, and studies of breeding areas and seasonal movement patterns have been completed (Barnett 1980, Grigg & Taylor 1980, Jenkins & Forbes 1985, Lindner 1994, Russell & Smit in prep.).

Estuarine (saltwater) crocodiles inhabit coastal estuarine areas, tidal wetlands associated with costal plains, as well as freshwater reaches and billabongs. Once hunted extensively for skins to the point where populations were thought to be in danger of collapse in some areas (Jenkins & Forbes 1985), the saltwater crocodile is now protected throughout the Northern Territory (NT). Research indicates that after introduction of protection measures in the NT, populations of saltwater crocodiles increased annually by around 6% between 1977 and 1988 (Jenkins & Forbes 1985). Crocodile populations within Kakadu National Park are believed to be very healthy (Lindner 1994).

14.2.3.4 Dugongs and cetaceans

Though little studied in the Van Diemen Gulf region, dugongs are regularly sighted feeding on sea grass beds surrounding Gardangal (Miles 1988, Guinea 1990, Morris 1996, Russell & Smit in prep.), and dugong and dolphins are regularly observed in Kakadu's rivers and coastal waters (Morris 1996, Russell and Smit in prep.). Small schools of the Australian snub fin dolphin (*Orcaella heinsohni*) (previously the Irrawaddy river dolphin) are regularly seen in the tidal sections of Kakadu's rivers (Morris 1996), and pods of Indo-Pacific humpback dolphins (*Sousa chinensis*) have been observed feeding in the mouth of the Alligator River (Arnold, pers com 2003). Other inshore dolphin species such as the bottlenose dolphin (*Tursiops aduncus*) are also found in nearby coastal habitats (Porter & Chilvers 2005) and are very likely to occur within Kakadu National Park. Pilot whales have also been observed in the waters of the Van Diemen Gulf adjacent to Kakadu (Morris 1996).

14.2.3.5 Fish

Between 1979 and 1989, considerable data was collected by the (then) NT Department of Primary Industry and Fisheries on the recreational barramundi *(Lates calcarifer)* fishery between the Adelaide and East Alligator Rivers (Griffin 1982, 1989). The project focused mostly on areas adjacent to the Arnhem Highway rather than coastal waters. However, this and a number of other studies on barramundi have shown the importance of mangrove and coastal environments to these species for a significant part of their life cycle (Griffin 1985). The reliance of barramundi, a species of cultural, recreational an commercial importance, on a range of marine and freshwater habitats highlights the close interaction of onshore and offshore environments in Kakadu and consequently the health of coastal waters to the health of much of Kakadu's aquatic fauna generally (Press et al 1995a,1995b)

Building on knowledge gained through prawn-trawl bycatch, demersal fish trawl catch, a small amount of *ad hoc* collecting and surveys (Midgley 1973, Pollard 1974, Bishop et al 1986, 1990, 2001, Davis & May 1979, 1989) the Museum and Art Gallery of the NT and Kakadu Park staff have been conducting fish and estuarine surveys in Kakadu coastal waterways since 1996 (Larson 1997, 1999a, 1999b, 2002, Russell & Smit in prep.). Survey results show that more than 300 estuarine and coastal fish species occur in the area but that there are very likely to be many more species that are not yet recorded. A basic inventory of what may be found in the coastal and marine environments of Kakadu National Park or the Van Diemen Gulf region more generally does not yet exist. In addition, almost nothing is known about the biology of most (non-commercial) marine and estuarine fish species found within and adjacent to Kakadu.

14.2.3.6 Birds

Several bird surveys have been conducted in the region by various groups, though the majority of these studies focus on estuarine and wetland habitats (Schodde 1973, Saenger et al 1977, Hergerl et al 1979, Bamford 1988). A report prepared by Chatto (2001) summarising the distribution and status of breeding seabirds in the NT documents preliminary observations of seabirds found in coastal and marine environments adjacent to Kakadu.

The foreshores and beaches of Kakadu National Park are a major staging point within Australia for many migrating birds that are commonly found throughout NT coastal environments including the beach stone-curlew, plovers, terns, sandpipers, pied and sooty oyster catchers, eastern curlew and whimbrel (Press et al 1995b, Chatto 2001).

Ocean-going birds such as the brown booby, great and lesser frigate bird, silver gull and up to 10 species of tern use the coastal region. Around 40 species of birds have been recorded along the coastal edge (Press et al 1995b, Russell and Smit in prep.).

Among the birds restricted to the estuarine and tidal areas of the Park are the chestnut rail, the collared kingfisher, or mangrove, kingfisher, the broad-billed flycatcher, the black butcherbird, the mangrove gerygone, or warbler, and the red-headed honeyeater. The great billed heron. large-tailed nightjar and collared kingfisher are also commonly associated with mangroves and have been listed as notable by Parks Australia (Roeger and Russell-Smith 1995). During the wet season egrets, ibises, herons and cormorants nest in large colonies in the mangrove tree-tops. Thirty-five species of waders have been recorded on the wetlands, many being winter migrants from the sub-Arctic region (Press et al 1995b).

14.2.3.7 Snakes

Three species of sea snakes have been recorded in the estuarine and tidal reaches of Kakadu’s rivers: the Darwin, Stoke’s and Hardwick's sea snakes (Press et al 1995b). Other aquatic snakes of interest in Kakadu’s coastal areas are the white-bellied mangrove snake, bockadam, and McCleay’s water snake, which all favour mangrove habitats and feed on crustaceans and fish (Press et al 1995b). The little file snake inhabits estuarine regions and feeds on crabs and small fish.

14.2.3.8 Seagrass

A major survey of inshore seagrass communities and adjacent habitats was undertaken in the southeastern Van Diemen Gulf adjacent to Kakadu National Park in November 2004 as part of a North Australian Marine Biodiversity Survey (Pyper 2005, Roeloffs et al 2005, Russell and Smit in prep). The project scope and objectives were to identify sea grass communities and map seagrass beds as well as collate a baseline of traditional ecological knowledge and developing productive working relationships between the Australian and Northern Territory Governments, researchers, and Indigenous people. A final report of the survey is in preparation and should be available during early 2007 (Russell & Smit in prep).

The majority of seagrasses found during the survey were in the intertidal habitats around Gardangal. No seagrasses were found on the extensive coastal mudflats of Kakadu other than at the entrance to the South Alligator River and west of Gularri (Point Farewell) near the mouth of the East Alligator River. Four species of seagrasses were recorded within and adjacent to Kakadu National Park: *Halophila decipiens* (the dominant species), and *Halodule uninervis*, *Halophila ovalis* and *Syringodium isoetifolium* which tended to be sampled together with *Halophila decipiens* (Russell & Smit in prep.).

Intertidal seagrass habitats at Gardangal mapped by Roeloffs et al (2005) as part of the survey comprise an estimated total area of 2126 hectares, all of which showed evidence of dugong feeding.

Subtidal seagrass beds at Gardangal recorded by Russell and Smit (in prep) are found principally at the northwestern and northeastern tip of the island. Beams trawls of subtidal areas at the northwestern tip of the island suggest a higher biomass of subtidal seagrasses here than anywhere else within Kakadu National Park boundaries (N Smit pers obs), however, more sampling is necessary to accurately determine the extent of these subtidal meadows. Marine turtles were observed at all subtidal seagrass meadows during the North Australia Marine Biodiversity Survey (Russell & Smit in prep.).

14.2.3.9 Mangroves

Mangrove forests are well developed in Kakadu National Park and cover an area of around 7,200 hectares, or about 3% of the Park's coastal area (Russell-Smith 1995). In 1979, the Wetlands Research Group of the Australian Littoral Society (now the Australian Marine Conservation Society) undertook a study on the tidal wetlands of Kakadu National Park (Hergerl et al1979). In 1981 the same group carried out work on mangroves in the Park (Hergerl et al 1982). This work built on several non-specific studies of mangroves and other estuarine flora in the region (Story 1969, 1973, 1976, Christian and Aldrick 1973, Schodde and Martensz 1973, Saenger et al 1977, Wells 1979, 1981). Subsequent work on mangroves in Kakadu has been undertaken by Davie (1985), and Schodde et al (1987).

A summary and status of the East Alligator mangrove transects as established by the Australian Littoral Society has been prepared by Saynor et al (2003). Numerous studies assessing changes in mangrove distribution within the Alligator Rivers region are summarised by Hall and Saynor (2000). These studies span environmental prehistory times (Woodroffe 1988, Clark and Guppy 1998) through to recent decadal changes (Cobb 1998, Cobb et al 2000, Heerdegen & Hill 2000, Winn 2001, Winn et al 2006) and show that the coastal environment is subject to change and highly dynamic in this region. Remote sensing based studies have provided baseline extent and height of mangroves and examined changes in mangrove distribution within Kakadu National Park (Lucas et al 2002). Studies examining responses to sea level rise indicate mangroves are likely to opportunistically colonise areas such as the South Alligator River floodplain if they become inundated with sea water thereby expanding the distribution of mangroves (Woodroffe 1990, Wolanski & Chappell 1996)

The mangrove transects established by the Australian Littoral Society in 1979 were relocated in 2002 and they will be re-surveyed in 2007 to further determine changes in mangrove distribution and species composition.

Mangroves grow along muddy tidal reaches of all the major coastal river systems in Kakadu as well as much of the coast (Russell-Smith 1995). Wells (1985) describes the mangroves of the coastal river systems as among the most species-rich in northern Australia, while Whightman (1988) lists 39 of the 47 mangrove species in the NT as occurring in the Park.

The region is not characterised by high levels of regional or local endemism, as most mangrove species found in Kakadu are widespread in Australia and throughout the Indo-Melanesian biogeographic region (Duke 1992). However Whiteman (1988) notes that three mangrove species of restricted occurrence in the NT and possibly a new species (known only from the Wildman River estuary), are found in the Park. A rare mangrove vine species has also been recorded from the South Alligator River.

Mangroves are important for stabilising the coastline, and they provide habitat for at least 75 species of birds (Morton & Brennan 1983). Colonies of black and little red flying foxes sometimes congregate in their thousands within mangrove forests, and 16 species of reptiles and amphibians (notably saltwater crocodiles and marine turtles) and many species of fishes are all dependent on mangrove habitats (Braithwaite et al. 1991, Griffin 1985). Mangroves also represent one of the richest of all habitats in terms of traditional food resources and add greatly to the quality of life of coastal people (Morris 1996).

14.2.3.10 Invertebrates

Almost all taxonomic knowledge of marine invertebrates (particularly major groups such as hard corals, sponges, polychaete worms and crustaceans) in the NT is derived from well-surveyed areas in Darwin Harbour and Beagle Gulf. In contrast the marine invertebrate fauna of Kakadu and neighbouring Van Diemen Gulf is very poorly known other than edible charismatic species such as mud crabs, prawns and clams (Hanley et al 1997, Davis and May 1989, Veron 2004, Willan and Dredge 2004). Work on estuarine crustaceans and other invertebrates in and adjacent to Kakadu has tended to be done opportunistically during fish surveys (Midgley 1973, Pollard 1974, Bishop et al 1986, 1990, 2001, Davis & May 1989, Larson 1997, 1999a, 1999b, 2000, 2002).

Hegerl et al (1979, 1982) provide preliminary information on mollusc and crustacean fauna associated with mangrove forests and tidal marshes in Kakadu. The North Australian Marine Biodiversity Survey undertaken in the southern Van Diemen Gulf region during 2004 also recorded a range of invertebrate fauna. A detailed report of the survey describing these invertebrate fauna will be available in 2007 (Russell & Smit in prep.).

14.2.4 Key challenges for management of Kakadu's coastal country

There have been a range of concerns raised by Traditional Owners and other Park managers over time in regards to management of the marine environment adjacent to Kakadu. These concerns include the following (Kiessling 2003):

- Need for better protection of natural and cultural values within the marine environment adjacent to Kakadu;
- Few opportunities for Bininj to guide the management of marine activities that have the potential to impinge on the cultural values of coastal and marine areas;
- Lack of scientific data on marine habitats and species adjacent to Kakadu;
- Unknown (possibly unsustainable) levels of use within marine and coastal environments within and adjacent to Kakadu;
- The impact of (legal and illegal) commercial fishing operations on marine habitats and species (both target species and bycatch) within and adjacent to Kakadu;
- The impact of high and/or unregulated numbers of recreational fishers on marine and coastal habitats and species within and adjacent to Kakadu;

- Difficulties associated with monitoring and surveillance of the Park's coastal boundary;
- Safety of visitors to coastal waters.

Several of these concerns are addressed in more detail below.

14.2.4.1 Commercial fishing

Commercial gill-netting for barramundi and threadfin salmon, and trapping of mud crabs was common along the length of Kakadu's coastline until the end of 1989 when commercial fishing was closed within Kakadu's boundary. Management regulations were first imposed on the commercial barramundi fishery in Kakadu during 1962, when inland waters were closed to gillnet fishing on a seasonal basis. A total closure was introduced in 1966, and today commercial fishing, including mudcrabbing, is totally banned within Kakadu's boundaries.

Barramundi netting is currently the main commercial fishery operating adjacent to Kakadu. The number of commercial barramundi fishing operations adjacent to the Kakadu coastline has increased in recent years from two to seven (as at 2004), and incidents of illegal fishing in the Park are known to occur. There are no data to determine the impact of commercial fishing on populations of target or non-target species (eg saltwater crocodile, sawfish, dugong and shark) within Kakadu (Kiessling 2003). However, Bininj have repeatedly raised concerns regarding the impacts of commercial and recreational fishing in adjacent marine waters on the natural and cultural values of the Park (ESS 1994).

To date no commercial fisheries or aquaculture enterprises are owned or undertaken by Indigenous people in waters adjacent to Kakadu, and the area is not currently represented within the system of Aboriginal Fisheries Consultative Committees established by the NT Fisheries Agency.

14.2.4.2 Recreational fishing and other forms of tourism

A range of fish targeted by recreational fishers such as threadfin salmon, jewfish and golden snapper occur in the marine environment adjacent to Kakadu and within the lower reaches of the Park's rivers. Barramundi may be found throughout Kakadu's rivers and the adjacent coastal waters. Many anglers travel to the mouth of the South Alligator River and fish around Gardangal and Djidbordu for reef fish (ESS 1994).

The potential pressure of recreational fishing activity species and environments in Kakadu has long been recognized (SSCERA 1988, Duff 1989). Although little information has been collated, anecdotal evidence and limited data collected by Park staff suggests that in recent years, numbers of recreational fishing boats, coastal sightseeing, tours and sport fishing activity has been growing (Kiessling 2003).

Recreational fishers are currently not licenced or regulated other than through catch limitations in the NT. Surveys of the recreational fishing catch and effort in the NT did not include Kakadu (Coleman 1998). However, the survey demonstrated that recreational fishers catch a far greater proportion (around six times) of landed catch than commercial fisheries. Specifically, recreational fishing by residents constitutes the majority of fishing effort in the NT, with Darwin Harbour accounting for close to half of all the recreational hours fished. Activity outside Darwin Harbour tends to be focused around the Alligator Rivers, Mary River, and adjacent coastal waters with most fishing activity occurring within 40 – 50 km of road access points (Coleman 1988). More than 40% of fishing effort in the Mary and Alligator Rivers and adjacent coastal waters is attributable to *visitors* to the NT (compared with NT *residents*), and together these rivers and coastal area account for around 11% of total fish caught by area across the NT (Coleman 1988). These figures strongly suggest that the recreational fishing effort within

Kakadu and adjacent coastal waters is likely to be substantial. Based on the assumption that recreational fishing will continue to grow in popularity, obtaining better information on recreational fishing effort and impacts in the Kakadu region is essential.

14.2.4.3 Research and data collection

Information on marine and coastal environments adjacent or near to Kakadu tends to be very limited, and research effort directed at marine/estuarine issues has been noted as inadequate (Smyth 1995). Information that is available tends to be *ad hoc* and narrowly focused, and consists largely of species lists with little reference to spatial or temporal variation in distribution and abundance, habitat associations, or general ecology. The conservation status at both regional and national levels of many species within the marine environment is also uncertain due to poor survey coverage around the northern Australian coast generally (Roeger and Russell-Smith 1995). This lack of information presents a major hurdle to effective conservation of Kakadu's coastal waters (Roeger & Russell-Smith 1995, Smyth 1995).

14.2.5 The way forward

In order to better understand the most appropriate and effective options for management of the marine waters adjacent to Kakadu, the following activities may be seen as a priority:

- Consultation with Bininj and other managers regarding marine conservation priorities;
- Mapping of key marine habitats and species with particular reference to species of cultural, conservation and/or economic significance;
- Collation of all *ad hoc* observations regarding levels of use of and visitation to marine and coastal environments, infringements and impacts arising from human activities;
- Development of a quantitative data collection (monitoring and reporting) methodology to determine levels of use and visitation to marine and coastal areas, measures of recreational effort and take and the degree of impact on species, populations and habitats arising from these activities. Focus data collection around usage of boat launching ramps, fish bins within the Park, and ad hoc visitor surveys;
- Detailed bathymetric and substrate mapping of the Van Diemen Gulf as a basis for better understanding coastal processes and benthic habitats, and to contribute to human safety in the region. The bathymetry of Van Diemen Gulf is shown on *Hydrographic Chart AUS 308 Goulbourn Islands to Melville Island*, which was published in 1968 from information gathered prior to 1966. Many parts of the Gulf have not been properly surveyed, including those areas adjacent to Kakadu;
- Detailed habitat mapping of reefs and seagrass beds around the southern Van Diemen Gulf, and seasonal monitoring of green turtle and dugong feeding. This work could be undertaken in conjunction with present monitoring of nesting populations of marine turtles currently being undertaken by Rangers and Traditional Owners of Kakadu National Park.

The North Australia Marine Biodiversity Survey has demonstrated that significant research can be undertaken as a collaborative effort between Traditional Owners and ranger groups. Based on experience gained through the Marine Biodiversity Survey, it is suggested that projects such as those outlined above may be undertaken by Bininj with advice and assistance where necessary from other Park managers and scientists.

Although Kakadu abuts the rich and diverse marine environment of Van Diemen Gulf, the Park's northern boundary is restricted to mean low water. As a result, marine and coastal values are not well represented or protected within the current boundaries of the Park and effective management of marine activities potentially impinging on Park values is consequently restricted.

As noted above, the waters of Van Diemen Gulf are under the responsibility of the NT Government whose jurisdiction extends up to 3 nautical miles seaward of established ‘baselines’ stretching from the Tiwi Islands to the Cobourg Peninsula. As a result, any research and management activity of coastal and marine environments beyond the boundaries of Kakadu National Park requires close cooperation with the NT Government.

Some of the most important features of Kakadu National Park are highly dynamic systems at the interface between saline and freshwater systems such as mangrove, wetland and floodplain environments. The interaction between land and sea environments is fundamental, so that human activities on land often have a direct influence on the health and productivity of offshore ecosystems. Likewise, human activities in the marine environment have the potential to impact species and habitats onshore. While almost the entire South Alligator River catchment is currently managed and protected within the boundaries of Kakadu National Park, the coastal and marine environments with which this catchment closely interacts are not. The high degree of linkage between marine and terrestrial environments in Kakadu highlights that consideration of conservation and management strategies beyond the Park’s coastal boundary are warranted.

14.2.6 References

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